NUMBER

T PHYSIOLOG

APRIL, 1948

CONTENTS

...ccumulation in the Cotton Plant at Low ...evels. F. M. Eaton and D. R. Eccles, ...cultural Experiment Station, College Sta- ... 169

...Curvature Responses of the Avena Coleop... ...nversely Applied Direct Current. A. R. ... University of Texas, Austin, Texas ... 185

...ter to the Germination of Corn and Cotton ... Smith, Harris Teachers College, St. Louis, ... 205

...nt Level on the Growth and Chemical Com... ...of Sweetpotatoes in Sand Cultures. O. A. ... W. S. Anderson, and M. Gilcher, Mississippi ...ral Experiment Station, State College, Mis- ... 225

...the Possibilities and Method of Breeding High... ...rn (Maize). Frederick R. Richey and Ray ..., U. S. Department of Agriculture Division ... Crops and Diseases, Knoxville, Tennessee ...mbia University, New York ... 235

Notes ... 255

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Volume 23 1948

PLANT PHYSIOLOGY

1948

In Memoriam

BURTON EDWARD LIVINGSTON

1875–1948

This volume of Plant Physiology
is dedicated to the memory of
Burton Edward Livingston

BURTON EDWARD LIVINGSTON

1875–1948

It is with profound sorrow that the American Society of Plant Physiologists records the passing on February 8, 1948, of Doctor Burton E. Livingston. This volume of Plant Physiology is dedicated to him in recognition of his distinguished record as a scientist and his life-long devotion to the promotion of science in general. In the dedication of this memorial volume to Doctor Livingston, the American Society of Plant Physiologists attests its enduring appreciation of his generous support of its aims and activities from the time of its organization. This volume is expressive in an intimate way of the high esteem and warm personal regard in which he was held by all his colleagues.

Doctor Burton E. Livingston was born February 9, 1875, at Grand Rapids, Michigan, and spent most of his boyhood in that part of the state. Through the great interest of his family in plants, he grew up with an unusually wide acquaintance with the out-of-doors and under the stimulus of this unique home environment Dr. Livingston soon became profoundly engrossed in and developed an early understanding of plants, their behavior and habitats. His youthful quest for knowledge concerning the living things about him was further fostered and rapidly systematized by availability of a splendid family library. In the home he also had access to simple microscopes and to a variety of tools. The extraordinary richness of nature, the beauty of the woods, fields, and streams in his native state, coupled with his natural boyhood interest and opportunities for study and experimentation, all served to shape the professional future in which Dr. Livingston attained such high distinction.

In grade and high school Dr. Livingston not only pursued his interest in biology but obtained a good foundation in languages and sciences in general of which he made such excellent use later as a leader in his chosen field of research. The herbarium begun in high school rapidly developed into a systematic scientific project. For some time following his high school study Dr. Livingston worked in a federal nursery where he became acquainted with practical problems. He left this position just prior to entering the university in order to spend an entire summer botanizing and enlarging his own herbarium.

Upon matriculation at the University of Michigan in 1894 he was immediately given considerable college credit in botany for his previous work. At Michigan he had the good fortune of working with such eminent botanists as V. M. Spalding and F. C. Newcombe. The latter was largely responsible for Livingston's decision to specialize in plant physiology, not in its narrow sense of indoor laboratory work but rather as it related also to soils, climate, plant distribution and natural habitats. Livingston soon became Newcombe's laboratory assistant and embarked upon his well known studies of the

dynamic environmental complexes of light, water, wind, and temperature. After obtaining the baccalaureate at Michigan in 1898, Dr. Livingston taught for a year at the Freeport, Illinois, high school. From among several graduate appointments tendered him, Livingston elected to enter the new, but already famous, University of Chicago in 1899 where he became one of a distinguished group of scholars who assisted Professor Charles Reid Barnes in developing plant physiology there.

Although Livingston completed his work for the Ph.D. degree in 1901, he remained as laboratory assistant and associate in botany until 1905. His book, *The Role of Diffusion and Osmotic Pressure in Plants,* published by the University of Chicago Press in 1903, is still an important summary of the field up to that time. It was during this period at Chicago that the writer was first privileged to know him as a tall, friendly, earnest young man who was unusually adept in experimental techniques of plant physiology.

Beginning in 1905, Dr. Livingston held various positions which were the preparatory period of his life work. He was in charge of fertility investigations in the Bureau of Soils, U. S. Department of Agriculture, Washington, D. C., until he accepted a position in 1906 with the Carnegie Institution of Washington, which was then being established. He became a staff member of its Department of Botanical Research and went to Tucson, Arizona, where he found conditions around the Desert Laboratory a great challenge to his interests. Here he first developed and used the porous porcelain atmometers in studying the evaporativity of the plant environment and the drying influence of sunlight. Then followed a year at eastern institutions and at the Missouri Botanical Garden, where he studied particularly the transpiration of greenhouse-grown cacti. In 1908 he traveled in Europe, spending time mainly with von Goebel at Munich, but also visiting Pfeffer's institute at Leipzig, Klebs at Heidelberg, and Hall at the Rothamsted Agricultural Experiment Station in England. Upon his return from Europe late in 1908, he attended the Baltimore meeting of the American Association for the Advancement of Science. At this time he visited D. S. Johnson's Botanical Garden at Homewood, which was then being made into the campus of Johns Hopkins University. He returned to the Desert Laboratory but in 1909 was tendered the chair of plant physiology at Johns Hopkins which he promptly accepted. In estimating personal influences of most importance to him during the years leading up to the Hopkins appointment, Dr. Livingston always acknowledged his special indebtedness to Newcombe, Barnes, Cowles, MacDougal, and Jacques Loeb.

In 1913 Dr. Livingston was made director of the Laboratory of Plant Physiology at Johns Hopkins, a position which he held with great distinction until 1940. As soon as the Johns Hopkins Laboratory of Plant Physiology was opened, it became a mecca for plant physiologists, not only from the United States but also from far-distant lands. About 140 graduate students completed advanced work in the laboratory during the period 1909–40, and the Ph.D. degree in botany was conferred upon 28 of these graduates. He and his students published nearly 300 papers during Livingston's tenure at

Johns Hopkins. Such problems as temperature, light intensity, three-salt nutrient solutions, the continuous renewal of culture solutions, foliar transpiring power, the daily march of transpiration, the seasonal march of soil moisture conditions, the water-supplying power of soils in relation to the wilting and withering of plants, the carbon dioxide-supplying power of the air, and the oxygen-supplying power of soils and its relation to seed germination are representative of topics pursued in his continuous and wide-ranging quest for new knowledge.

Doctor Livingston also contributed substantially to the advancement of plant physiology and ecology by the invention or improvement of many excellent instruments for exact quantitative measurements of dynamic environmental factors. The porous porcelain atmometers, cylinders, spheres, and plates, in both black and white, with standardized techniques, made possible the accurate measurements of evaporativity in various sorts of environments. Batteries of black and white atmometers were shipped all over the world to assist ecologists and physiologists in evaluating the effects of atmospheric humidity and sunlight upon water relations of plants. Livingston's auto-irrigators provided means for control of soil moisture conditions in pot culture experiments and his soil points of porous porcelain were devised to measure the water-supplying power of soils. These soil points were extremely accurate in their readings when used at a definitely known hygrometric water content. In addition to these many types of porous instruments, he made and sold to laboratories many supplies that could not be obtained elsewhere. These included leaf clips used in transpiration experiments, hygrometric paper, permanent color standards, tripartite color standards, and standard evaporating surfaces with which leaves could be compared. A reconditioning service was also maintained to clean, refinish, and restandardize apparatus for laboratories not equipped to perform these necessary operations for themselves. These instruments and services were widely used and the influence of the Johns Hopkins Laboratory was thereby extended to all parts of the world.

In addition to the book published in 1903 and his numerous scientific contributions in journals, he published with Forrest Shreve a book on *The Distribution of Vegetation in the United States as Related to Climatic Conditions* (1921). In 1918 he edited an English translation of Palladin's *Plant Physiology*, which had appeared in three editions by 1926. Dr. Livingston was a skillful scientific writer and he contributed to various journals in an editorial capacity. Notable among these were *The American Scholar*, *Physiological Researches*, *Botanical Abstracts*, and *Plant Physiology*. He exerted considerable influence on the editorial policies of the latter journal, upon whose editorial committee he served diligently for many years. He deserves a great deal of credit for the general excellence of content and appearance of the early volumes of *Plant Physiology*.

Doctor Livingston rendered inestimable service to The American Society of Plant Physiologists in the first years of its existence. He was very sympathetic toward its ideals, and it was through his interest and advice that the

new society was affiliated with the American Association for the Advancement of Science in October, 1924, before the society was six months old and before it had held its first annual meeting. Affiliation gave the plant physiologists representation on the council of the association. Livingston's advice often kept the new society out of difficulties and lent encouragement to its officers and members. His contributions were so highly esteemed that the first Charles Reid Barnes honorary life membership was awarded Dr. Livingston at Philadelphia in 1926. In 1927, when the society celebrated the Stephen Hales anniversaries at Nashville by founding the Stephen Hales award, Dr. Livingston not only made the largest single contribution to the fund for the Hales endowment but did it in a manner to induce generous gifts by many others.

In 1934 he was elected president of the American Society of Plant Physiologists. During that year the constitution was revised, and many changes were made in the procedures, all in the direction of more liberal and democratic management of the society's affairs. Recognition of his long-continued interest and his vital contributions to plant physiology through the Johns Hopkins Laboratory was given Dr. Livingston by conferment of the Stephen Hales award in 1946. He was too ill by December 1947 to deliver his address in response to this award at the annual meeting of the society.

Although he belonged to many organizations, his primary devotion was to the American Association for the Advancement of Science. He became its permanent secretary in 1920 and served for three successive terms, until 1931. It was the writer's privilege to be associated with him in the office of the association in Washington and also in the Johns Hopkins Laboratory in 1923. It was always a marvel as to how one person could carry two such heavy obligations without apparent physical impairment. Dr. Livingston seldom admitted that he was tired, yet he always carried a burden too heavy for one man's shoulders. He served the association for three years as general secretary (1931–34) and throughout the whole period of his connection with it, he was a member of its Executive Committee, helping to shape important policies during a long period of phenomenal growth. Few men have served the American Association for the Advancement of Science so long and so well.

During Dr. Livingston's term as permanent secretary of the American Association for the Advancement of Science he placed in effect many of the society's most successful projects including the Annual Science Exhibition, the Association Press Service, the Association Prize, the Secretaries' and Academy Conferences, and the plan of printing the association's General Program. He also made the association a strong bulwark of all state academies of science. The membership of the association and the number of affiliated societies doubled during Dr. Livingston's term as secretary. Important, too, have been the imponderables of enthusiasm, administrative acumen, and selfless devotion which he brought to the association and so effectively communicated to others associated with him in its guidance. He was a prime mover in placing fiscal affairs of the association upon their present

secure basis and in obtaining substantial contributions to its permanent endowment. Dr. Livingston was also active in the affairs of the National Research Council, the American Academy of Arts and Sciences, the American Philosophical Society, the American Society of Naturalists, the Botanical Society of America, and the Ecological Society of America.

Dr. Livinston's death leaves his many students, colleagues and friends with a deep sense of personal loss.

CHARLES A. SHULL

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CARBOHYDRATE ACCUMULATION IN THE COTTON PLANT AT LOW MOISTURE LEVELS[1]

FRANK M. EATON AND D. R. ERGLE

(WITH TWO FIGURES)

Received July 11, 1947

The growth and development of the cotton plant is sharply curtailed during periods of limited water supply. During such periods the plant wilts severely but it loses few leaves and again resumes growth when water is available. As originally undertaken the investigation reported in this paper had as its object the finding of whether cotton belongs among those plants that gain in carbohydrate levels under conditions of drought or among those that lose. Stated otherwise, is photosynthesis greater or less than utilization during periods of limited moisture supply? This general question bears on the mechanism of drought resistance, on possible causes of the reported (**18**) high boll shedding rates in dry seasons, and, finally, on the relation of carbohydrate supply to the susceptibility of the cotton plant to Phymatotrichum root rot in dry summers (**9**). Investigations are in progress on relations of carbohydrate levels and drought to the properties of cotton fibers. The initial objective is dealt with in this paper by assembling the chemical data that have accumulated during the course of collateral inquiries.

Review of literature

No one, at least in recent years, has undertaken a general review of the literature on the influence of drought on the accumulation of carbohydrates in plants. The summary that follows does not include all of the available references nor does it include the many observations on the reactions to wilting in detached leaves. It does, however, serve to illustrate the marked diversity between plants in their carbohydrate responses to drought and, also, the fact that there is a marked diversity in the reaction between tissues within given plants. Several opinions on the relation of carbohydrate accumulation to drought resistance are cited and there are included a few references to the effect of drought on the relative growth of roots and plant

[1] Approved as Technical paper no. 1042 of the Texas Agricultural Experiment Station.

tops. Mention is made also of several papers dealing with the influence of desiccation on photosynthesis and respiration.

CLEMENTS (**2, 3**) found higher concentrations of starch in the leaves of soybean, sunflower, and potato in a dry summer than in a normal one but in soybean the concentrations of sugars were not increased. Hemicellulose was increased by drought in leaves of soybean, unchanged in sunflower, and reduced in potato. In these plants the weight of roots, relative to stems and leaves, was markedly increased by drought. This fact indicates that drought increased the relative rate of translocation of carbohydrates to the roots and also stimulated the relative rate of synthesis of structural elements from these carbohydrates. This latter suggestion is supported by CLEMENT's finding that sugar concentrations (starch not determined), were much lower in the roots in the dry year than in the normal year.

Using intact plants, WADLEIGH, GAUCH, and DAVIES (**30**) showed with the progress of soil desiccation that starch disappeared rapidly from the leaves of potted Red Kidney beans. After watering, the starch levels exceeded those in the leaves of control plants within 24 hours. They considered, in keeping with SPOEHR and MILNER (**26**), that increased amylolytic activity might be involved in the disappearance of starch. In later work, however, WADLEIGH and AYERS (**31**) found that the concentrations of sugars, as well as starch, decreased with drought and that this decrease occurred in both the leaves and stems.

GRANFIELD (**12**) noted rapid accumulations of carbohydrate reserves in alfalfa roots with low soil moisture or low temperatures that limited growth, i.e., accumulation exceeded utilization. He stated that the increases in carbohydrates and nitrogen in buds was closely associated with increases in bound water and reduction in free water. WILLARD (**34**) working with alfalfa found periods of dry weather to be associated with unusual increases in the dry weight of the roots.

Relative to the area of the tops WEAVER (**32**) found the area (but not necessarily the weight) of corn roots in a dry soil to be almost twice that of roots in a moist soil. Cotton plants (**6**) grown in large soil cans and allowed to wilt between each application of water were found to have root weights equaling 30% of the above ground vegetative parts, while as the roots of plants kept moist weighed 40% as much as these vegetative parts.

ROSA (**20**) in 1921 reported reducing sugars to be higher on the fresh weight basis when cabbage, lettuce, and tomatoes were grown on dry soils. Starch was changed but little in cabbage and lettuce and markedly reduced in tomato. He regarded cold-hardy plants as those possessing "ability to initiate changes whereby the stability and water-retaining power of the protoplasm and consequently hardiness are increased." LOOMIS (**14**) has made reference to the changed appearance of the protoplasm of hardened alfalfa and sweetclover and suggested that differentiation of the protoplast and resistance to precipitation might be found to be dependent in part upon higher sugar concentrations.

Opuntia phaeacantha gathered at hot, dry Tucson, Arizona, was found by SPOEHR (**25**) to have low hexose sugars (0.06% on fresh weight) and high total polysaccharides (3.50%) whereas at cool, humid Carmel, California, hexose sugars were substantially higher (0.52%) and total polysaccharides substantially lower (1.94%). These extremes had little effect upon pentoses or pentosans. Elsewhere SPOEHR (**24**) concluded that pentose sugars accumulate in Opuntia sp. only under conditions of low moisture and disappear with increasing moisture. With the advent of summer rains in mid-July the concentrations of pentose sugars decreased to less than half whereas the hexose sugars, which were originally present in about the same concentration, dropped only from 10.45 to 8.60%.

The grasses in general appear to accumulate carbohydrates when moisture limits growth. With flowering and the advance of drought during the summer SAMPSON and MCCARTY (**21**) found carbohydrates, especially those polysaccharides hydrolyzed by saliva, to accumulate in *Stipa pulchra* growing near Berkeley, California. In the previous autumn the summer accumulation of carbohydrates disappeared rapidly with the advent of rains and renewed vegetative growth. JULANDER (**13**) likewise found increased concentrations of sucrose and glucosans in roots of bluebunch wheatgrass, bluebunch fescue, and bluestem after drought. In greenhouse experiments, Bermuda grass and buffalo grass accumulated much greater concentrations of sucrose and glucosans in a dry plot than in a wet plot. There were marked increases in the concentration of reducing sugars as well, but in terms of weight per plant, these increases were minor. When grass plants with roots were placed in closed glass tubes and submerged, JULANDER found that those from his dry greenhouse plot withstood for longer periods a temperature of 48° C. He likened this effect to hardening to cold and drought and associated it with carbohydrate accumulations.

MILLER's data (**17**) on winter wheat in Kansas during the dry springs of 1933 and 1934 and in the somewhat wetter spring of 1935 are summarized below as averages on the dry basis for the entire tops of two varieties at the three weekly sampling dates ending May 11, 2 and 9, respectively, for the three years.

	1933	*1934*	*1935*
	%	%	%
Available moisture	0.80	1.70	3.20
Reducing sugars	1.35	0.52	0.61
Nonreducing sugars	2.53	4.76	2.66
Starch	0.67	0.06	0.13
Sum of sugars and starch	4.55	5.34	3.40
Hemicellulose	15.38	14.95	14.14
Total nitrogen	2.57	3.03	3.01

Much variability was found between dates in both the proportion and quantities of the various constituents, but the two varieties were consistent in showing sugar levels to have been increased by limited moisture. Non-

reducing sugars predominated in the late spring as they did during the winter-period of high accumulation. The amount of hemicellulose in the tops as expressed in grams per 100 plants increased until harvest and fully justified MILLER's conclusion: "It seems that none of this carbohydrate was utilized in any manner by the wheat plant." VASSILIEV and VASSILIEV (**35**), also found increased sugars with low moisture. Their conclusion that the hemicelluloses in wheat may be one of the sources for the formation of sugars may not have been well supported since they included starch in their hemicellulose fractions. According to MILLER's data (**17**) the concentrations of starch in wheat, though characteristically low, are sometimes substantial.

CLEMENTS (**4**) has shown sugar levels in sugar cane to be negatively correlated with growth and moisture supply.

Working with apples MAGNESS, REGEIMBALL and DEGMAN (**15**) observed that drought conditions severe enough to decrease the rate of fruit growth to half that of irrigated trees had little effect on carbohydrate accumulation in leaves, bark, and wood. In keeping with the above, SCHNEIDER and CHILDERS (**22**) found that drought greatly reduced the rate of apparent photosynthesis of attached apple leaves and markedly increased the rate of apparent respiration; in some instances the latter exceeded the former. Further evidence of increased respiratory rates with decreasing moisture is provided by SMITH (**23**) who, using a vacuum desiccator, found increased rates of CO_2 evolution from detached leaves of snowdrop and young stems of Tropaeolum until about 30% of the moisture was withdrawn. Below 30% moisture CO_2 evolution decreased to complete dryness. No increase in CO_2 evolution was found in young stems of peony or asparagus.

Below certain moisture levels, the rate of photosynthesis seems always (**16**) to be reduced progressively with drying. YUNKER (**36**) found in the instance of corn that the dry weights of unit leaf areas increased with decreasing soil moisture. VERDUN and LOOMIS (**28**) found CO_2 absorption by wilted corn leaves to average 37% of turgid leaves. Light intensities above 3000 f.c. did not increase apparent photosynthesis nor did the sugar accumulation in plants without ears decrease it.

ERGLE (**10**) and ERGLE, HESSLER, and ADAMS (**11**) have followed carbohydrate accumulation in cotton plants through two summers. Although they made no direct comparisons between moist and dry plants it seems reasonable that drought was an important factor in the upward trends they observed.

Methods

As described in greater detail elsewhere (**7**), all samples were extracted with hot 80% alcohol. Sugars were determined by the WILDMAN and HANSEN procedure (**33**), starch by diastatic hydrolysis, and hemicellulose by HCl hydrolysis of the residue. All of the root bark samples and the leaf samples reported in tables I, II, III, VIII, and IX were placed while fresh in hot 80% alcohol. Elsewhere the samples were preserved by drying at

70° C. under forced draft. The writers are indebted to PARKE, DAVIS & COMPANY for supplying them with undiluted diastase of exceptionally low sugar content.

STARCH MEASUREMENTS BY VARIOUS METHODS

Data to be presented are consistent in showing that starch, as determined by diastatic hydrolysis, accumulates in the stems and roots, but not in the leaves, of the cotton plant under conditions of inadequate water supply. Inasmuch as diastase is well known to hydrolyze not only starch but some related compounds, importance was attached to the extent to which the reducing material found in the cotton tissues after diastatic hydrolysis originates from starch. Using both diastase and DENNY's (**5**) calcium chloride extraction procedure, a series of comparisons were made between the yields of "starch" from various tissues of differently treated cotton plants. The results of these comparisons were alike in that the yields by diastase were always substantially greater than those obtained by calcium chloride extraction. If the assumption were made that most, or all, starch can be extracted quantitatively from finely ground plant tissue with calcium chloride the low recoveries by this method could be interpreted as showing that drought not only increased starch accumulation in the roots but also the accumulation, sometimes to an even greater extent, of other materials that also yield reducing substances when hydrolyzed by diastase. Before drawing such a conclusion it seemed expedient to make starch analyses by additional methods.

For this undertaking, four relatively large samples of leaf and root bark tissues from cotton plants growing in wet and dry plots were collected and extracted with alcohol. GUTHRIE and CARROLL L. HOFFPUIR of the SOUTHERN REGIONAL LABORATORY at New Orleans cooperated in the undertaking by making in their laboratory starch analyses of these samples by the STEINER-GUTHRIE (**27**) procedure. They also measured starch in the final solutions from the STEINER-GUTHRIE procedure by use of the colorimetric reagents of PUCHER and VICKERY (**19**). The standard for this colorimetric comparison was cotton-leaf starch isolated from the final solutions. Corrections were made for the moisture and ash contents of the isolated starch. The results obtained by these latter methods, both of which are regarded as being specific for starch, together with the writers' results by diastase and calcium chloride extraction, are presented in table I.

In a comment on the values obtained by their method, GUTHRIE and HOFFPUIR indicated that this procedure sometimes gives results as much as 1 percentage value too low when a sample contains less than 10% of starch; this being due to negative rotating substances that are not completely removed. They further suggested that due to difficulty in obtaining pure starch from the cotton samples for their reference standards, the colorimetric values may have been a little high. With these qualifications in mind it is evident by table I that the agreement between the diastase, STEINER-GUTHRIE, and colorimetric values is fairly good whereas the values by calcium-chloride extraction are consistently low.

TABLE I

STARCH IN COTTON-LEAF AND ROOT-BARK SAMPLES AS DETERMINED IN DUPLICATE BY FOUR METHODS OF ANALYSIS. PERCENTAGES OF STARCH ARE REPORTED ON THE DRY WEIGHT OF THE MATERIAL AFTER EXTRACTING SUGARS WITH ALCOHOL. COLLEGE STATION, TEXAS, 1944

DESCRIPTION	DIASTASE	STEINER-GUTHRIE	COLORIMETRIC	$CaCl_2$ EXTRACTION
	%	%	%	%
Leaf blades—irrigated	6.1	7.4	7.7	2.0
	5.9	7.4	7.7	1.8
Leaf blades—dry	1.8	0.9	1.8	0.6
	1.7	0.9	1.9	0.4
Root bark—irrigated	5.1	3.1	4.1	2.9
	4.9	3.2	4.1	2.8
Root bark—dry	6.0	4.6	5.4	3.4
	6.2	4.8	5.4	3.2
Means	4.7	4.0	4.8	2.1

To summarize, it appears to the writers that the increases in the polysaccharide fraction in cotton root bark as a result of drought represents starch, primarily, rather than dextrins or other substances, and also that the diastatic analytical procedure provides a creditable measure of starch accumulation.

Results

PLANTS GROWN AT COLLEGE STATION, TEXAS

The data of table I show that wilted leaf blades of cotton plants from dry plots collected at 6 P.M. had concentrations of starch only one-third as great as did turgid blades collected from irrigated plants. At the same hour the root bark from the dry plants had 20% more starch than that from the irrigated plants.

TABLE II

CARBOHYDRATES AND NITROGEN IN STONEVILLE 2B ROOT BARK IN WET AND DRY PLOTS AT COLLEGE STATION, TEXAS, JULY 1944. THE DRY PLANTS SHOWED SOME WILTING AT 8 A.M. AND WERE MARKEDLY WILTED AT NOON. EXPRESSED AS PERCENTAGES OF RESIDUAL DRY WEIGHT; I.E., FRESH WEIGHT MINUS MOISTURE AND SUM OF DETERMINED CARBOHYDRATES

HOUR	MOISTURE	HEXOSES	SUCROSE	STARCH	SUM	TOTAL NITROGEN
Wet						
6 A.M.	77.0	4.32	8.44	7.76	20.53	0.87
Noon	75.2	4.58	8.85	8.02	21.45	0.96
6 P.M.	75.0	4.80	8.90	7.95	21.65	0.94
Mean	75.7	4.57	8.73	7.91	21.21	0.92
Dry						
6 A.M.	73.7	5.05	8.64	7.08	20.76	0.90
Noon	72.8	6.44	9.40	8.66	24.49	1.04
6 P.M.	71.4	6.41	9.64	8.59	24.64	1.06
Mean	72.6	5.97	9.23	8.11	23.30	1.00

Additional root bark samples were collected from other parts of the same plots at noon and 6 P.M. on July 26 and at 6 A.M. on July 27. These results, table II, are presented on the basis of residual dry weights. The averages for the three collections show somewhat higher concentrations of hexoses, sucrose, and starch in the roots of the dry than in those of wet plants. Greater total carbohydrate was found at noon and 6 P. M. than the following morning at 6 A.M. (sunrise 5:45 A.M.). The root bark of the dry plants contained greater concentrations of total nitrogen than did that of the wet plants.

TABLE III

CARBOHYDRATES IN THE BARK OF THE TAP ROOTS OF COTTON PLANTS ON MODERATELY MOIST SOIL AND IN PLANTS THAT HAD SHOWN MARKED TO SEVERE WILTING FOR FIVE WEEKS. THE SAMPLES WERE COLLECTED AT 2 P.M. EXPRESSED AS PERCENTAGES ON FRESH WEIGHT AND ON RESIDUAL DRY WEIGHT

TREATMENT	HEXOSES	SUCROSE	STARCH	HEMI-CELLULOSE	TOTAL NITROGEN	MOISTURE IN ROOT BARK
			FRESH WEIGHT BASIS			
Irrigated	0.69	1.22	2.44	3.53	0.34	75.1
	0.89	1.20	2.34	3.20	0.36	73.8
Mean	0.79	1.21	2.39	3.36	0.35	75.5
Dry	1.88	2.23	6.86	5.52	0.66	57.9
	1.69	2.55	6.94	4.87	0.72	57.7
Mean	1.78	2.39	6.90	5.20	0.69	57.8
Mean difference	0.99	1.18	4.51	1.84	0.34	17.7
			RESIDUAL DRY WEIGHT BASIS			
Irrigated	4.04	7.14	14.29	20.67	1.98	
	5.34	7.19	14.00	19.17	2.16	
Mean	4.69	7.16	14.14	19.92	2.07	
Dry	7.31	8.67	26.67	21.47	3.56	
	6.54	9.87	26.87	18.84	2.79	
Mean	6.92	9.27	26.77	20.16	2.68	
Mean difference	2.23	2.11	12.63	0.24	0.61	

In a previous year the concentrations of carbohydrates found in the root bark of cotton plants that had wilted severely each day for a period of five or six weeks prior to sampling were compared, table III, with those of plants from adjacent irrigated rows. The latter plants, however, were not abundantly supplied with moisture for the reason that the soil was relatively impermeable to irrigation water and the roots of a nearby group of oak trees withdrew rapidly such irrigation water as did penetrate into the root zone. The same oak trees were largely responsible for the severity of the wilting of the dry plants. Because of the severity of the drought, the carbohydrate accumulations in these plants probably represent an extreme condition.

All carbohydrate fractions were notably more concentrated, table III, in the root bark of the dry plants than in those under irrigation and there was also a great difference in the moisture content of the root bark. For this reason the data of table III are reported both on the basis of fresh weight of tissue and on the basis of residual dry weight. Residual dry weight was calculated by subtracting from the fresh weight the weight of moisture, sugars, starch, and hemicellulose. As expressed on residual dry weights, there was more sucrose than reducing sugars under both treatments, but the two types of sugar were increased to nearly the same extent by drought. Drought nearly doubled the concentration of starch but was without effect on the concentration of the hemicellulose fraction.

TABLE IV

SUGAR, STARCH, AND HEMICELLULOSE IN THE MIDDLE THIRD OF COTTON STALKS WITH A FULL LOAD OF BOLLS AND PLANTS LIMITED BY DEFRUITING TO TWO BOLLS PER PLANT IN IRRIGATED AND UNIRRIGATED (LITTLE WILTING) FIELD PLOTS AT COLLEGE STATION, TEXAS, IN 1945. THE SAMPLES WERE COLLECTED AT 2 P.M. EXPRESSED AS PERCENTAGES OF DRY WEIGHT

	Hexoses	Sucrose	Starch	Hemicellulose	Moisture in fresh sample
	%	%	%	%	%
Full load of bolls					
Irrigated					
Aug. 1	5.45	1.51	4.07	15.82	66.5
Aug. 20	5.61	0.72	3.83	16.12	62.3
Unirrigated					
Aug. 1	4.53	3.86	5.46	15.57	63.4
Aug. 20	6.64	0.25	5.39	16.08	62.0
2 bolls per plant					
Irrigated					
Aug. 1	5.58	1.19	6.16	16.15	66.6
Aug. 20	4.23	1.37	13.88	15.05	59.1
Unirrigated					
Aug. 1	9.78	1.68	9.82	14.47	64.2
Aug. 20	4.08	1.29	14.53	15.11	55.9
Mean of irrigated	5.22	1.20	6.98	15.78	63.6
Mean of unirrigated	6.25	1.77	8.80	15.31	61.4

In table IV there are comparisons of the sugars, starch, and hemicellulose in the middle third of cotton stalks from irrigated and unirrigated plots in 1945. A number of rains occurred during the summer of 1945 and there was little wilting in the "dry" plots. The data are consistent in showing in both full-load and 2-boll plants a greater accumulation of starch in the stalks from the dry plots. The differences in sugar levels were only slightly in favor of the dry plants and not always consistent. In this table as in table III there is no evidence that hemicellulose concentrations had been changed by drought.

The data of table V represent accumulations in the leaves of cotton plants (fig. 1) grown in the greenhouse with an abundant supply of moisture compared with plants that wilted daily by reason of only small daily

FIG. 1. Moist, left, and dry, right, cotton plants, showing the effects of moisture supply on growth and the characteristics of moderate wilting. These two plants, which were of like size on Jan. 22, were from the groups harvested on Feb. 21 for analyses reported in table V. Subsequent to Jan. 22 the dry plants received only small daily additions of water.

water additions between Jan. 22 and Feb. 20, 1946. These data, like those of table I, show a much greater accumulation of starch in the moist than in the dry leaves, the hexose sugars, however, were higher in the dry leaves. Little sucrose was present. The limited moisture supply apparently decreased the hemicellulose concentration. The amylolytic activity in the dry leaves was four times as great as in the wet leaves.

PLANTS GROWN AT SHAFTER, CALIFORNIA

Data from Shafter, California, are reported in table VI (leaves from two varieties) and table VII (leaves, stems, and roots of Acala). The two sets of samples were from different plots.

The samples reported in table VI show drought to have resulted in

TABLE V

CARBOHYDRATES IN LEAVES OF WET AND DRY GREENHOUSE PLANTS AFTER THE DRY PLANTS HAD WILTED DAILY FROM JAN. 22 TO FEB. 20. EXPRESSED AS PERCENTAGES OF DRY WEIGHT

TREATMENT	MOISTURE	HEXOSES	SUCROSE	STARCH	SUM	HEMICELLULOSE	RELATIVE AMYLOLYTIC ACTIVITY*
	%	%	%	%	%	%	
Wet	81.4	2.21	0.12	6.72	9.05	8.07	0.26
Dry	71.8	3.03	0.00	1.84	4.87	6.37	1.00

* In fresh leaves by method of SPOEHR and MILNER (26).

large increases in hexose sugars and large decreases in starch in the leaves of both Acala P 18–C and Stoneville 2B. The hemicellulose concentrations were 17% higher in both the Acala and Stoneville leaves from the dry plots than in those from the wet plots. All carbohydrate fractions were higher in dry stems and roots than in wet ones, table VII.

Total nitrogen, tables VI and VII, was decreased by drought in the leaves. In the stems and roots no effect of drought on total nitrogen is indicated. Soluble nitrogen, on the other hand, was increased by drought in all tissues.

Plants grown in the Blacklands, Temple, Texas

Field experiments on the relation of moisture supply and carbohydrate accumulation to the susceptibility of cotton plants to phymatotrichum root

TABLE VI

Carbohydrates and nitrogen in leaves of Acala P 18–C and Stoneville 2B cotton in irrigated and very dry plots at Shafter, California, July 24, 1946. Expressed as percentages of dry weight

Treatment	Moisture	Hexoses	Sucrose	Starch	Sum	Hemicellulose	Nitrogen		Dry weight per leaf
							Total	Soluble	
	%	%	%	%	%	%	%	%	gm.
Wet									
Acala	78.8	0.88	0.53	3.95	5.36	2.45	3.64	0.45	1.28
Stoneville	77.7	0.61	0.72	3.05	4.38	2.93	3.11	0.67	1.34
Dry									
Acala	72.8	1.40	0.18	0.43	2.01	2.88	3.11	0.86	1.46
Stoneville	67.9	1.60	0.36	0.94	2.90	3.45	2.72	0.79	1.08

rot were conducted on Houston black clay at Temple, Texas, during 1942 and 1944. The root rot data with more complete descriptions of the organization of the experiments are provided elsewhere (9).

1942

In 1942 there were four treatments fertilized (800 pounds of 9–3–3 fertilizer per acre) and unfertilized plots in both irrigated and unirrigated blocks. Four root-bark samples, each of 15 plants, from each of the four treatments were taken between 10 and 11 on the morning of Aug. 17 following a 5 acre–inch application of water on the irrigated plots on July 10 and again Aug. 10, and following rains of 0.48 and 1.56 inches on Aug. 12 and 16, respectively. At no time during the summer did the dry plots show any appreciable degree of wilting but the irrigated plants were much larger than the dry plants and it may be noted that the tap roots of the dry plants weighed 40% less than those of the wet plants.

Limited water supply in 1942, table VIII, resulted in increased concentrations of hexoses, sucrose, and starch and an increase of 56% in the sums of these carbohydrates in the root bark. Fertilization also increased

carbohydrate concentrations but it seems possible that much of this gain might also have been associated with differences in moisture supply; i.e., the larger fertilized plants would more rapidly have exhausted soil moisture. The weight of the tap roots in the fertilized blocks was greater by 18% than the weight in the unfertilized blocks. A slightly higher concentration of

TABLE VII

CARBOHYDRATES IN MAIN-STALK LEAVES, MIDDLE THIRD OF STEMS, AND LARGE ROOTS (LIFTED WITH SHOVEL) OF ACALA P 18–C IN WET AND EXTREMELY DRY PLOTS (2 MORNING AND 2 AFTERNOON SETS OF SAMPLES COMBINED) AT SHAFTER, CALIFORNIA, ON JULY 16–17 AND AUGUST 6–7, 1946. EXPRESSED AS PERCENTAGES OF DRY WEIGHT

TISSUE, TIME, AND TREATMENT	MOISTURE	HEXOSES	SUCROSE	STARCH	SUM	NITROGEN		WEIGHT PER LEAF, ½ STEM, OR ROOT
						TOTAL	SOLUBLE	
	%	%	%	%	%	%	%	gm.
LEAVES								
Wet								
July	79.3	0.77	0.05	1.76	2.58	3.26	0.64	1.31
Aug.	77.8	0.60	0.80	1.64	3.04	3.31	0.62	1.36
Dry								
July	75.5	0.82	0.08	1.30	2.20	3.18	0.78	1.29
Aug.	67.1	0.94	0.09	1.26	2.29	2.98	0.78	1.35
STEMS								
Wet								
July	79.0	2.59	0.41	0.91	3.91	0.96	0.41	6.6
Aug.	74.6	4.58	0.26	1.39	6.23	0.60	0.26	16.0
Dry								
July	70.0	5.61	2.33	2.10	10.04	0.82	0.36	6.0
Aug.	61.9	5.82	0.62	4.38	10.82	1.06	0.53	6.0
ROOTS								
Wet								
July	74.6	1.42	1.76	1.87	5.05	0.74	0.34	17.2
Aug.	69.5	2.02	1.49	2.90	6.41	0.56	0.16	31.0
Dry								
July	65.1	2.45	4.02	5.19	11.66	0.66	0.66	16.7
Aug.	60.4	3.75	2.96	8.71	15.42	0.75	0.33	16.9
MEAN OF:								
Wet	75.8	2.00	0.80	1.75	4.55	1.57	0.40	12.2*
Dry	66.7	3.28	1.68	3.82	8.78	1.58	0.57	8.0*

* Mean fresh weight of stems plus leaves in grams per plant: wet 1606, dry 335.

hemicellulose is indicated in the dry than in the irrigated plants but this difference is without statistical significance and, further, it disappears when the data are recomputed (not shown) on the basis of residual dry weights.

1944

The 1944 summer was much more favorable for drought experiments than was 1942. There were no rains of consequence between June 12 and Aug. 27 but there were some late season rains starting with 1.91 inches between Aug. 27 and Aug. 30. One acre-inch of water was applied weekly to the

TABLE VIII

CARBOHYDRATE LEVELS IN THE BARK OF THE TAP ROOTS OF COTTON GROWING AT TEMPLE, TEXAS, IN 1942. EXPRESSED AS PERCENTAGES OF FRESH WEIGHT

	Moisture in root bark	Hexoses	Sucrose	Starch	Hemi-cellulose	Total nitrogen	Weight of tap roots
	%	%	%	%	%	%	*gm.*
Treatments							
Wet							
Unfertilized	79.0	0.56	1.02	0.84	9.12	0.130	17.1
Fertilized	78.0	0.68	1.07	0.86	9.63	0.152	21.7
Dry							
Unfertilized	75.4	1.11	1.53	1.03	9.79	0.136	11.2
Fertilized	75.4	1.05	1.98	1.16	10.45	0.201	12.2
Factorial Summary							
Wet	78.5	0.62	1.04	0.85	9.38	0.141	19.4
Dry	75.4	1.08	1.75	1.10	10.12	0.169	11.7
Effect of drought	−3.1	0.46	0.71	0.25	0.74	0.028	−7.7
Unfertilized	77.2	0.83	1.27	0.93	9.46	0.132	144.4
Fertilized	76.8	0.86	1.52	1.02	10.04	0.176	17.0
Effect of fertilizer	0.4	0.03	0.25	0.09	0.58	0.044	2.6
Percentage Change as a Result of:							
Drought	−3.0*	74*	68*	29*	7	19*	−40*
Manure	−0.5	4	28*	11	6	3*	18*

* Statistically significant by odds of 19 to 1 or better.

irrigated plots between July 15 and Aug. 24. The four treatments: irrigated, irrigated plus manure, dry, and dry plus manure, were randomized in each of 10 blocks. Triplicate root bark samples, each of ten roots, were collected from each of the four treatments between 10 and 11 in the morning on each of four successive dates (fig. 2).

The hexose sugars, sucrose, and starch concentrations, figure 2, were higher in the root bark of the plants growing in the dry plots than in those

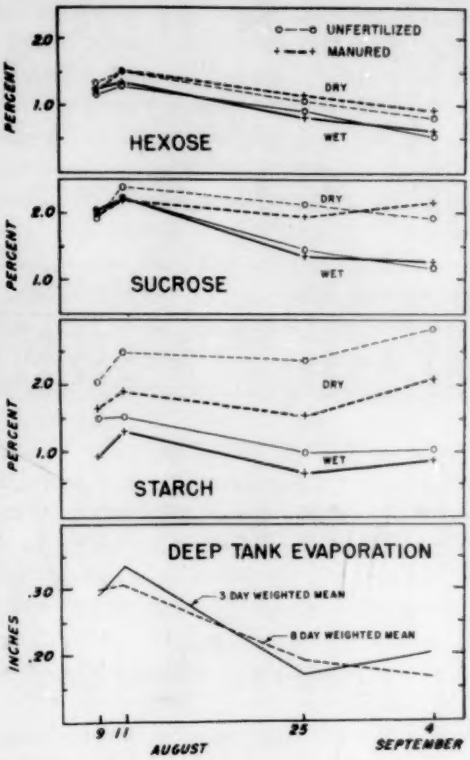

FIG. 2. Carbohydrate concentrations in the root bark of cotton plants in wet and dry plots with and without manure at successive dates and two weighted evaporation means. Temple, Texas, 1944.

in the wet plots. In both the wet and dry plots the concentrations were substantially higher than in 1942. Drought increased starch concentration by 29% in 1942 (samples were collected following a rain of the preceding day) whereas in 1944, when there were no rains, starch was 91% higher. On the other hand, the increases in the two classes of sugars were great in 1942 (74 and 68%) and minor in 1944 (19 and 24%).

Manuring (6.4 tons of oat straw, dry weight, plus 100 pounds of nitrogen per acre) was without significant effect on either sugars or total nitrogen but the manure resulted in a substantial reduction in starch concentration.

As shown in figure 2 marked variations occurred in 1944 in the carbo-

TABLE IX

MEANS OF CARBOHYDRATE, NITROGEN, AND MOISTURE CONCENTRATIONS IN ROOT BARK (FOUR DATES), AND SOIL MOISTURE (FIVE DATES) AT TEMPLE, TEXAS, IN 1944. EXPRESSED AS PERCENTAGES OF FRESH WEIGHT

	HEXOSE	SUCROSE	STARCH	TOTAL NITROGEN	ROOT-BARK MOISTURE	WEIGHT OF BARK PER ROOT	SOIL MOISTURE
	%	%	%	%	%	*gm.*	%
TREATMENTS							
Wet							
Unfertilized	1.00	1.69	1.27	0.242	74.6	11.8	23.7
Manured	1.02	1.72	0.95	0.268	75.7	13.3	23.5
Dry							
Unfertilized	1.18	2.13	2.46	0.365	70.1	8.4	19.9
Manured	1.21	2.07	1.79	0.359	71.0	9.0	18.8
FACTORIAL SUMMARY							
Wet	1.01	1.70	1.11	0.255	75.2	12.6	23.6
Dry	1.20	2.10	2.12	0.362	70.6	8.7	19.4
Effect of drought	0.19	0.40	1.01	0.107	−4.6	−3.9	−4.2
Unfertilized	1.09	1.90	1.86	0.304	72.4	10.1	21.8
Manured	1.12	1.91	1.37	0.314	73.4	11.2	21.6
Effect of manure	0.03	0.01	−0.49	0.010	1.0	1.1	−0.6
PERCENTAGE CHANGE AS A RESULT OF:							
Drought	19*	24*	91*	42*	−6.1*	−31*	−18*
Manure	3	0	−26*	3	1.4*	11*	− 3

* Statistically significant by odds of 19 to 1 or better.

hydrate concentrations between the successive sampling dates and these variations followed similar trends under the various treatments. All carbohydrate concentrations increased between Aug. 9 and Aug. 11, even though there was an intervening irrigation of the wet plots. Furthermore, all concentrations decreased between Aug. 11 and 25 without an intervening rain of any consequence. It being evident that these changes were largely independent of substrate variables, an examination has been made of climatic factors. Other than for the rough characterization of days as clear, partly cloudy, or cloudy, light intensity data were not available, and the available temperature and humidity data did not lend themselves well to integration. BRIGGS and SHANTZ (1), however, have found the Weather Bureau type of deep tank to provide a relatively good summary index to weather factors. Use is made in figure 2 of this variable. Carbohydrate accumulation being in some measure cumulative, two weighted evaporation means have been tested for goodness of fit. One is a 3-day and the other an 8-day weighted mean. For the 3-day means, the evaporation of the first day prior to sampling is given a weight of 3, the second day of 2, and the third day a weight of 1. Similarly the 8-day weighted means were obtained by multiplying the evaporation of the first day prior to sampling by 8, that of the second day by 7, . . . , and that of the eighth day preceding by 1, and dividing the sums of these products by 36.

The evaporation rate was high for the three days preceding the samples of Aug. 11, and the days were characterized as clear. Relative to Aug. 9 all carbohydrate concentrations increased. Aug. 21, 22, and 23 were characterized as cloudy, the evaporation rates were relatively low and the carbohydrate levels were found to have decreased by Aug. 25. Sept. 1 was clear and Sept. 2 and 3 were partly cloudy. Somewhat higher starch concentrations were found on Sept. 4. The rain of 1.54 inches on Aug. 26, 27, and 28, was apparently of only transitory significance in terms of carbohydrate levels.

The foregoing data show additional carbohydrate accumulation with increased evaporation rates and the evaporation rates evidently correlate well with light intensities. Whether the accumulation of carbohydrates in the roots was principally a result of more rapid photosynthesis or of depressed rates of utilization (respiration and tissue building) is not evident from the data. There is some reason for believing that depressed utilization is involved. Unpublished shade experiments have shown that reductions of outdoor light intensities to about half of full exposure tends to reduce carbohydrate levels without influencing the yield of cotton plants. More extreme reductions in light intensity (8) greatly reduced carbohydrate levels and fruitfulness but had a minor effect on vegetative growth.

Discussion

The cotton plant possesses a notable ability to survive long and intense drought and to recover with the loss of comparatively few leaves when water

is again supplied. Throughout the foregoing data large increases were found in starch and sugar concentrations in the stems and roots of cotton under drought conditions. In the leaves, on the other hand, hexose sugars were increased but starch was reduced. On a relative basis the gains in hexoses in the leaves during drought were substantial but in actual amount these gains appear very minor. On the basis of fresh weight only fractions of one percentage value are represented and the total sugars in leaves that had wilted daily for long periods were below 1%. Although labile sugars must be regarded as essential to the maintenance of living protoplasm, it is difficult for the writers to believe that these small gains in leaf sugars found in the cotton leaves could have contributed greatly to the ability of the plants to endure drought.

The foregoing conclusion finds some support in the comparisons of table VI between leaves of Acala and Stoneville cotton. The latter cotton had somewhat higher sugar concentrations in its leaves than did the Acala and yet it wilted more severely. It may be that this extra accumulation of sugar aided the Stoneville in withstanding without death or irreversible change its more extreme tissue desiccation but it evidently did not contribute very much to prevention of desiccation. A lesser development of the Stoneville tap root, than of the Acala, has been observed by G. J. Harrison at Shafter.

Insofar as may be concluded from the analyses of tissue masses, as distinct from sieve tubes, phloem, or other individual tissues, the movement of carbohydrate from the leaves to the stems of both the wet and dry cotton plants was against relatively high concentration differentials. Such unidirectional, or polar movement, is well known in cotton and as shown in table VII the concentration differentials were greater in the dry than the moist plants. The ability of the cotton plant to expend the necessary metabolic energy for polar movement is evidently not lessened by drought conditions. At Shafter, California, in August the ratios of concentrations of hexose sugars in leaves, stalks, and large roots were on fresh weights respectively 0.13 : 1.16 : 0.62% in plants on wet soils and 0.31 : 2.22 : 1.49% in plants on dry soils. The corresponding total-carbohydrate ratios were 0.67 : 1.58 : 1.95 (wet) and 0.75 : 4.13 : 6.11 (dry).

Summary

In cotton leaves, drought caused an increase in hexose sugars, variable effects on sucrose, and large reductions in starch concentrations. In stems and roots, on the other hand, there were always moderate to large increases in the concentrations of hexoses, sucrose, and starch. On the basis of averages of leaves, stems, and large roots the concentrations for the plant as a whole were doubled by protracted drought. Drought thus appears to depress carbohydrate utilization by the cotton plant to a greater extent than it does photosynthesis.

Drought resulted in both plus and minus changes in hemicellulose concentrations in leaves, according to conditions of growth, but caused no significant differences in stem and root tissues.

The carbohydrate concentration differentials between leaves and stems were greater in the instance of plants on dry than on moist soils, thus indicating that drought did not interfere with polar transport.

In summers with enough rainfall to prevent evident or frequent wilting, irrigation increased growth substantially.

The authors are indebted to NEIL E. RIGLER for collaboration in the fore part of this investigation and to E. W. LYLE for valuable cooperation in connection with experiments at Temple, Texas.

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ELECTRICAL AND CURVATURE RESPONSES OF THE AVENA COLEOPTILE TO TRANSVERSELY APPLIED DIRECT CURRENT[1, 2]

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(WITH SEVEN FIGURES)

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Introduction

The effects of applied current on curvature are apparently related to the problems of hormone transport and growth in the Avena coleoptile. Only inconsistent results have been obtained by the limited number of investigators who have published in this field.

CLARK (**3,4**) passed 0.8 μampere at 1.5 volts for 1 hour through forty 3-millimeter coleoptile sections placed between agar blocks. He maintained that this treatment did not influence the longitudinal transport of auxins even though the inherent electrical polarity of the sections was changed. Careful analysis of the experimental procedure used by CLARK, and even his interpretation, reveal them subject to serious criticism (**6**). CHOLODNY and SANKEWITSCH (**2**) have demonstrated that elongation of isolated Avena coleoptiles can be altered by applied direct current of 10^{-7} to 10^{-6} amperes. They observed an acceleration of growth, which lasted for a short time and, in most cases, was followed by a definite retardation of growth when the current was directed from the base to the apex. Similar current flow in the opposite direction retarded elongation of the coleoptile in most instances. These results are not in agreement with CLARK's data.

KÖGL (**8**) was able to influence Avena coleoptile curvature by applying current. He used decapitated plants and a current of 0.0008 milliampere. A moistened silk thread attached to a cube of agar containing auxin was used as one contact. This cube of agar was placed on one side of the decapitated coleoptile. The second contact was attached to the basal portion of the plant. KÖGL's results show that the coleoptiles reacted to a given quantity of growth hormones by a 12-fold more extensive bending when the agar cube was connected to the negative pole than when it was connected to the positive pole. Recently, DUBUY and OLSEN (**6**) reported experiments in which they applied 30 μamperes for 1 minute. Their contacts were placed on the same side of the coleoptile, 1 and 6 millimeters below the apex. This longitudinal application of current induced bending which was independent of the direction of the current flow. SCHRANK (**11**) has demonstrated that the Avena coleoptile responds to a direct current of 5 to 20 μamperes applied transversely for 2 minutes to a 5 millimeter apical segment by bending toward the electropositive side of the current applying circuit and by establishing a transverse electrical polarity. These data (**11**) show that the rate and

[1] Supported by the University of Texas Research Institute.

[2] The second of a series of papers on this subject.

magnitude of the curvature manifested are dependent on the intensity of the applied current, and that the direction of bending and the orientation of the polarity are determined by the direction of the current flow.

The present experiments are an extension of these earlier studies.

Apparatus and methods

Most of the details concerning the experimental procedure, laboratory conditions, technique of growing and handling the oats, and the apparatus employed were described in an earlier paper (**10**). Only a few specific features need to be recalled.

All experiments were performed under a ruby glass neon light in a dark room with the temperature controlled. Only coleoptiles of the Victory Strain *Avena sativa* (U. S. Department of Agriculture, C.I. 2020)[3] were used. A bridge type circuit (**9**) with two 6 volt lead storage batteries in series as the current source was used to apply the current. Current was measured with a Leeds and Northrup type HS galvanometer calibrated so that 5 scale divisions equalled to 1 μampere. Several measurements of resistance across transverse sections of the coleoptile were made with a Weston Model 785 Industrial Circuit Tester. Contact was made by the same method as for applying current. Resistances varying from 270,000 to 440,000 ohms were observed. This means that in order to get the required current the IR drop across the coleoptile would vary from 2.7 to 4.4 volts. Glass tubes 1 millimeter in diameter were used as the contacts with Shive's solution in tap water as the contact medium. Only the droplets of solution, which extend out of the open end of the glass tubing contacts, were permitted to touch the coleoptiles.

Two pairs of isoelectric ($\pm$ 0.5 mv) zinc–zinc sulphate electrodes were used. These were placed in the usual glass cups. See figure 1 of (**10**). One pair was employed for applying the current and the second pair for measuring the resultant electrical changes. This was done so that the polarization of the electrodes caused by the applied current would not be included in the measurement of the electrical responses. The electrical measurements were made with a duBridge amplifier (**5**).

Experimental results

Direct current applied transversely to intact coleoptiles 5, 10, and 15 millimeters below the apex

These experiments were designed to determine the effects of applying direct current transversely to intact coleoptiles 5, 10, and 15 millimeters below the apex. All plants were permitted to rest in the apparatus for 30 minutes preceding the experiments. Ten minutes after the beginning of each experiment the current was turned on and the position of the coleoptile tip was read on the horizontal ocular micrometer scale. A current of 10

[3] The seeds used in this investigation were generously supplied by the U. S. Department of Agriculture.

μamperes was applied for 10 minutes in all experiments. Readings of the tip position, electrical polarity, and temperature were repeated at 5-minute intervals. However, for convenience in plotting curves for publication, 10-minute intervals were frequently used.

Curve I in figure 1A shows the typical electrical response 5 millimeters below the apex. Electrical changes were measured by the same contacts, in

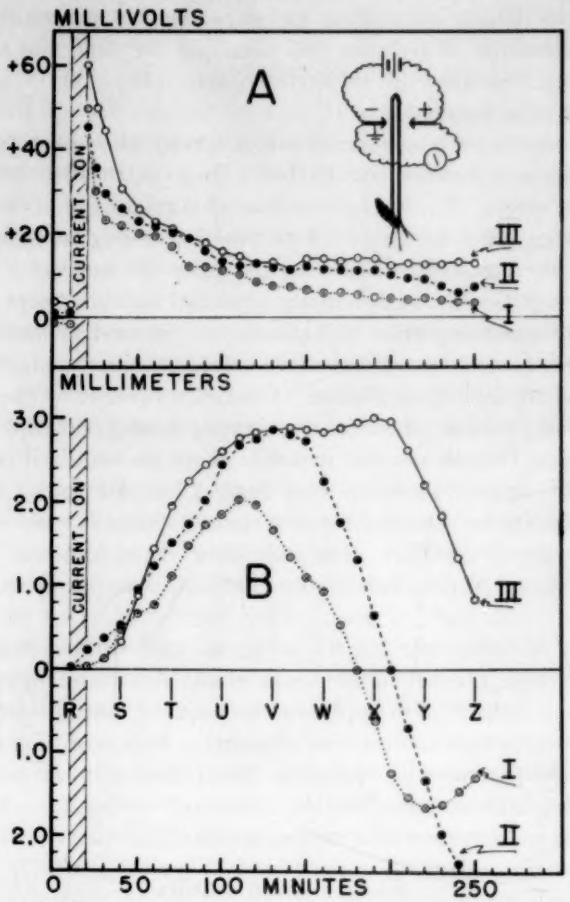

FIG. 1. Effects of transverse application of 10 μamperes for 10 minutes to the Avena coleoptile on: (A) transverse electrical polarity; (B) bending of the same coleoptiles. Curve I. Current applied 5 mm. below the apex. Curve II. Current applied 10 mm. below the apex. Curve III. Current applied 15 mm. below the apex.

the same position, that were used for applying current. The grounded contact in the measuring circuit is shown in the inset of figure 1A. It is the same as the negative contact of the current applying circuit. All E.M.F. curves[4] are plotted to show the variation of the opposite contact with respect to ground.

[4] More data are needed before these curves can be called polarization curves. See LUND and BERRY (9).

In curves II and III of figure 1A the current was applied 10 and 15 millimeters below the apex, respectively. The curves obtained in this series of experiments are, in general, very similar. (Compare curves I, II, and III.) They are also very much like the curves previously published (**11**). The chief variation noted in these curves is in the magnitude of the first reading after turning off the current. In 13 experiments of the series from which curve I was taken, the maximum electrical change was 55 millivolts, while the minimum was 30 millivolts (the average is 42 millivolts). When the current was applied 15 millimeters below the apex, a greater change in electrical polarity was noted. (See curve III, fig. 1A.) Subsequent data (fig. 5) bear on this point.

It is important to emphasize that the electrical phenomena measured in these experiments were due to the coleoptile tissue and *not* to the contacts or electrodes. Removal of the current applying electrodes from the circuit had no effect on the measurements, and a short circuiting of the contacts with the current applying electrodes in the cups always gave a zero reading.

Curve I in figure 1B shows the bending of the coleoptile as measured by following the tip when the current was applied 5 millimeters below the apex. This curve is plotted so that the graph above the zero line indicates a curvature toward the electropositive side of the current applying circuit, while the curve below the zero line represents bending in the opposite direction. All of the subsequent curves showing bending are plotted in the same way. The maximum curvature in the initial direction (toward the electropositive side) was reached 100 minutes after turning on the current. This period is longer than the average of 80 minutes in this series (fig. 6). In most of the experiments the process of the reversal of the curvature, as shown by the peak of curve I above the zero lines, was not so abrupt. Curves II and III in figure 1B show the bending of the coleoptiles whose electrical response is represented by the corresponding curves in figure 1A. When the current was applied 10 millimeters below the apex (Curve II), a longer time was required for the maximum curvature to be reached and also for the tip to return to the zero position. In curve III (current applied 15 millimeters below the apex) still more time is required (fig. 6). It will also be noted that the second bending toward the electronegative side starts only after the electrical polarity has decreased to a relatively small value.

The fact that curves II and III reach a maximum greater than attained by curve I is not necessarily an indication of greater curvature. Since the region of curvature in the coleoptiles II and III is farther below the apex, the radius of the curvature arc is longer than in plant I. Subsequent data show (table I) that a given quantity of current induces curvature more effectively when applied 5 millimeters below the apex than when applied to more basal sections.

Control experiments prove that these curvatures are caused solely by the applied current and not by other environmental factors. For example, application of the current in the opposite direction gave duplicate but reversed results.

All of the experiments represented by figure 1 were performed at a temperature of 23.5 (± 1.5) degrees centigrade. The data for curves I, II, and III come from experiments performed at 22.0 (± 0.1), 23.1 (± 0.15), and 22.9 (± 0.2) degrees centigrade, respectively.

Since the movement of the apex is not a measure of actual curvature, it does not give all of the facts about electrically induced bending. For this reason additional observations were made. These are shown in figures 2, 3, and 4, which were drawn by plotting the points obtained by using a combination of a horizontally placed ocular micrometer in a horizontal microscope mounted on a rack and pinion with a vertical scale. Points were plotted at 2 millimeter intervals along one side of the coleoptile. At the apex 1 millimeter intervals were used. The numbers underneath the drawings indicate hours after the beginning of current application. Successive

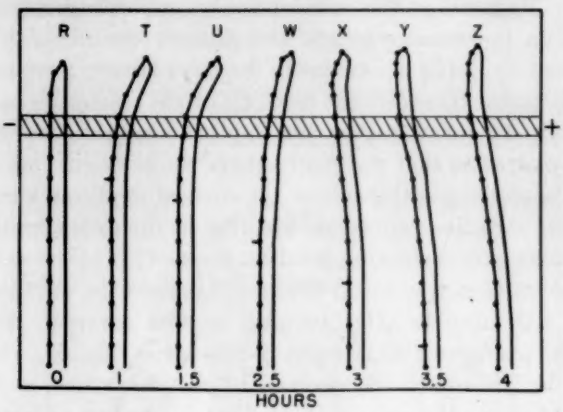

FIG. 2. Successive stages of Avena coleoptile curvature after transverse application of 10 μamperes for 10 minutes. Current applied 5 millimeters below the apex.

coleoptile positions R, S, T, etc. correspond to points similarly marked on the zero line in figure 1B. Current was applied to the region indicated in the figures. Several significant facts are revealed by comparison of the coleoptile positions. First, the portion of the coleoptile apical to the contacts is responsible for most of the initial curvature toward the electropositive side of the current applying circuit. Second, the zone of initial curvature moves toward the base. This is shown by noting the position of the most apical point (marked in figs. 2, 3, and 4) that is in a vertical line with the points below it. Third, the portion of the coleoptile basal to the contacts is responsible for the second curvature toward the electronegative side of the current applying circuit. Fourth, the zone of the second curvature apparently also moves toward the base (compare positions X, Y, and Z in figures 2 and 3). Finally, it should be pointed out that the section of the coleoptile apical to the current applying contacts becomes straight again. This is clearly shown by positions X, Y, and Z.

The coleoptile positions U in figures 2 and 3 show about the same magni-

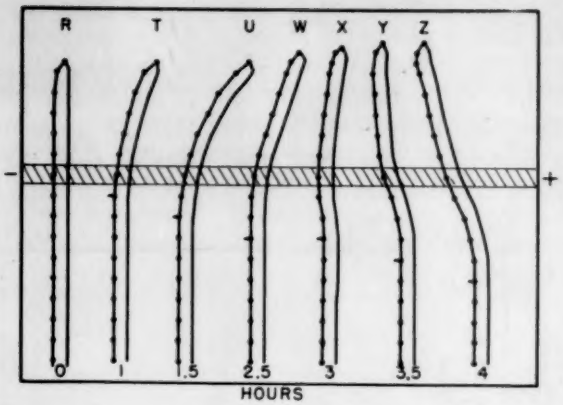

FIG. 3. Successive stages of Avena coleoptile curvature after transverse application of 10 μamperes for 10 minutes. Current applied 10 millimeters below the apex.

tude of curvature in the initial direction. In this case, application of the current 10 millimeters below the apex induced bending as effectively as applying it 5 millimeters below the apex. This is an exception to the general rule (table I).

VARIATION IN ELECTRICAL RESPONSE WHEN THE CURRENT IS APPLIED AT DIFFERENT DISTANCES FROM THE APEX

Curves II and III of figure 1A indicate that there is a variation in the electrical response of the different regions along the longitudinal axis of the coleoptile when a given current is applied for a unit of time. The curves in figure 5 show this variation. Each of the curves in this figure is an average of 10 or more experiments.

In general, the electrical curves are very similar, differing only in a few aspects. Curve V, from experiments in which the current was applied 20

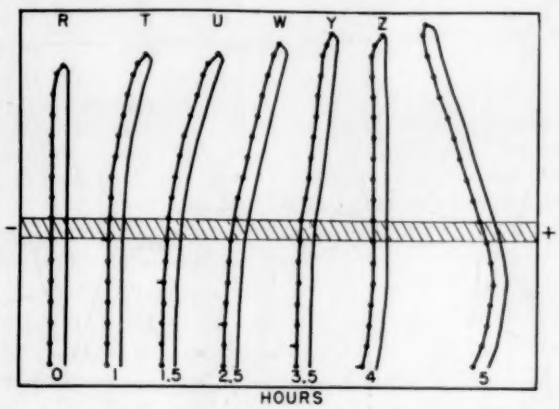

FIG. 4. Successive stages of Avena coleoptile curvature after transverse application of 10 μamperes for 10 minutes. Current applied 15 millimeters below the apex.

millimeters below the apex, shows the maximum change in polarity. This point below the apex is within the region of active elongation in coleoptiles of this length (**1, 14**). The magnitudes of the electrical changes shown by curves III, IV, and VI (contacts 10, 15, and 25 millimeters below the apex) are quite similar. It will be noted, however, that the initial slope shown by curve IV is somewhat less than the average and that shown by curve III is more than average. Current applied 5 millimeters below the

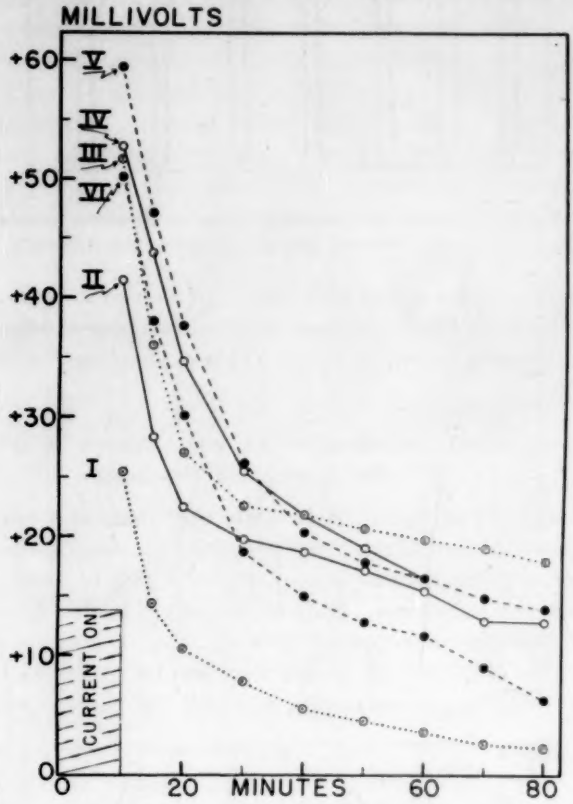

FIG. 5. Electrical polarities induced by applying a given current (10 μamperes for 10 minutes) transversely to the Avena coleoptile at various distances below the apex. Each curve represents an average of 10 or more experiments. Current applied at the following distances below the apex: Curve I, 2 mm.; Curve II, 5 mm.; Curve III, 10 mm.; Curve IV, 15 mm.; Curve V, 20 mm.; Curve VI, 25 mm.

apex results in a smaller initial electrical change than equal current applied more basally. This is shown by curve II. As indicated in curve I, the smallest electrical response was obtained when the current was applied 2 millimeters below the apex. Two interesting observations can be made at this point. (1) During growth of coleoptiles longer than 20 millimeters, the apical 2 millimeters scarcely elongate. (2) Since the diameter of the coleoptile 2 millimeters below the apex is less than in the more basal regions, there is less coleoptile tissue between the contacts.

VARIATION IN CURVATURE WHEN CURRENT IS APPLIED AT DIFFERENT DISTANCES FROM THE APEX

Data in figure 1B indicate that 10 μamperes applied transversely to the coleoptile for 10 minutes at different distances below the apex results in curvature variations. These differences are shown in figure 6. Each of the curves is an average of 10 or more experiments. These curves correspond to the electrical curves in figure 5. A comparison of the curves I through V establishes the following fact: As the distance from the apex for applying

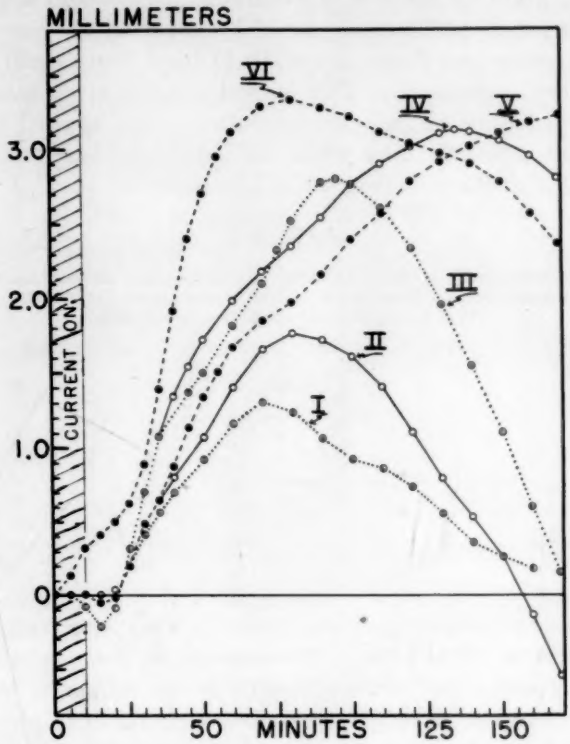

FIG. 6. Bending induced by applying a given current (10 μamperes for 10 minutes) transversely to the Avena coleoptile at various distances below the apex. Each curve represents an average of 10 or more experiments. Current applied at the following distances below the apex: Curve I, 2 mm.; Curve II, 5 mm.; Curve III, 10 mm.; Curve IV, 15 mm.; Curve V, 20 mm.; Curve VI, 25 mm.

current is increased, the time required for the coleoptile to reach its maximum curvature in the initial direction is also increased. Curve VI, representing curvature when current is applied 25 millimeters below the apex, is an exception to this statement. In this instance the maximum curvature is attained in the same time required for plants to which current is applied 5 millimeters below the apex.

It is apparent from figures 2, 3, and 4 that the position of the curvature zone is dependent on the region of current application. This means that

these curves cannot be used for comparing magnitudes of curvature, because they were obtained by plotting the coleoptile tip position on a horizontal scale. If it is assumed that the region of greatest bending is located the same distance below the apex as the contacts, then certain simple calculations can be made. Curve II in figure 6 (current applied 5 millimeters below the apex) shows the maximum tip displacement of 1.75 millimeters from its original position. Taking 1.75 millimeters as the short leg and 5 millimeters as the longer leg of a right triangle, then the angle opposite the short leg (angle of curvature) is equal to 19.3 degrees. This should approximate the maximum curvature which was induced by applying the current. Angles derived in the same way from curves III, IV, and V are equal to 15.7, 11.6, and 9.1 degrees, respectively. This indicates that a given quantity of current is more effective in inducing curvature when applied to the apical sections of the coleoptile than when applied to the basal regions. These calculations led to the following set of experiments.

TABLE I

CURVATURE EXPRESSED IN DEGREES INDUCED IN THE AVENA COLEOPTILE BY APPLYING 10 μAMPERES FOR 10 MINUTES AT VARIOUS DISTANCES BELOW THE APEX. FIVE EXPERIMENTS SELECTED AT RANDOM

CONTACTS, MM. BELOW APEX	5	10	15	20	EXP. NO
Curvature in degrees	15	8	4	2	1
	10	6	6	5	2
	13	12	6	3	3
	10	6	3	2	4
	11	9	7	4	5
Average	11.8	8.2	5.2	3.2	

Four plants were used in each experiment. They were carefully selected for uniform length (30 ± 1 mm.), straightness, development of root system, etc. As in previous experiments, current was applied at the designated distances below the apex. Proper precautions were taken to prevent the zinc sulphate from being carried to the plants by the current. After the current had been applied, the coleoptiles were left in holders under the filtered neon light until they reached their maximum curvature in the initial direction. For example, plants to which current was applied 5 millimeters below the apex were allowed 80 minutes before the curvature was measured. (In curve II of figure 6 the maximum curvature was reached 80 minutes after current application.) The time allotted to plants to which the current was applied at other distances from the apex was similarly determined from the appropriate curve in figure 6. At the end of the designated time, curvature was measured by the JUDKINS method (**7**). Table I gives the results from five experiments selected at random. These data confirm the evidence that current applied to the apical regions is more effective in inducing curvature than when applied to the basal regons. WILKS and LUND (**15**) have

reported similar findings. The calculated angles are too large because the point of beginning curvature is several millimeters below the contacts at the time of maximum curvature (figs. 2, 3, and 4). It will be noted that differences between the calculated angles correspond rather closely to the differences between the measured ones.

Variation in the length of coleoptiles

When the coleoptile reaches 35 to 40 millimeters in length, elongation of the most basal zones becomes very limited or ceases altogether (**1, 14**). With this fact in mind, a comparison was made between the effects of applying current 25 millimeters below the apex to coleoptiles 30 and 35 millimeters long. Figure 7 gives the results in the form of average curves. The curves in figure 7A show a greater electrical change in 30 millimeter plants (curve I) than in the longer ones.

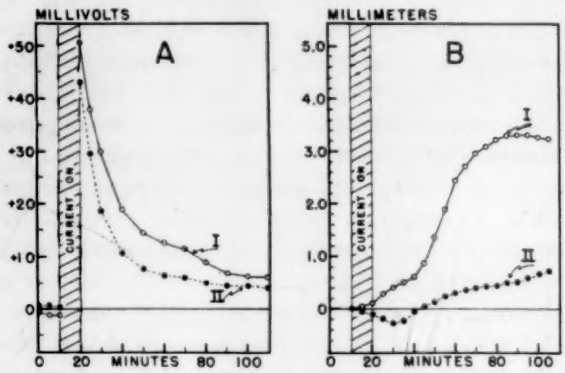

FIG. 7. Effects of applying a given current (10 μamperes for 10 minutes) 25 millimeters below the apex of Avena coleoptiles of different lengths. Each curve represents an average of 10 or more experiments. A. Electrical polarities in millivolts. Curve I, 30-mm. coleoptile; Curve II, 35-mm. coleoptile. B. Corresponding curvatures of plants shown in 7A.

Similarly, the curves in figure 7B, which correspond to the electrical curves in figure 7A, show that a given quantity of current applied 25 millimeters below the apex is much more effective in inducing curvature in the shorter and younger plants (curve I is from 30-millimeter plants).

Discussion

Results of experiments reported in an earlier paper (**11**) have demonstrated the following two facts: (1) Bending and electrical polarity changes can be induced in the Avena coleoptile by the transverse application of 5 to 20 μamperes for 2 minutes to the apical 5 millimeters. (2) The direction of the curvature and the orientation of the established polarity are dependent on the direction of the applied current flow.

The bending is always toward the positive pole in the applying circuit.

Since the active portion of the auxin molecule is an anion, it should be transported toward the electropositive pole and thus result in a bending toward the electronegative pole. The previously reported and present experimental findings are directly opposite to this, which means that they do not fit into the original WENT (**13**) KÖGL (**8**) conception of electrophoretic transport. On the basis of these facts, several other possibilities might be suggested: (1) The auxin molecule is transported as a positively charged particle; (2) the applied current influences auxin transport by a method other than electrophoresis; (3) the applied current affects the auxin-growth linkage in some way other than transport.

The present experiments confirm the previous findings (**11**), and prove that bending can be induced by transverse current flow through any 2-millimeter longitudinal section (fig. 1B, 2, 3, 4, and 6). Table I shows that a given quantity of current induces curvature more effectively when it is applied to apical sections than when applied to basal regions. THIMANN (**12**) has demonstrated a gradient of auxin distribution along the longitudinal axis of the coleoptile with the highest concentration in the apical 2 millimeters. These facts extend support to the idea that the applied current produces its effects via the hormone mechanism. From figures 2 and 3 it is evident that the zone of curvature moves toward the base. This suggests that the hormones are transported across the coleoptile by the applied current. The present investigation was not intended primarily to prove or disprove this suggestion. Experiments relating specifically to this point are in progress and will be published later.

Since the potential difference which was applied to the coleoptiles in these experiments (2.7 to 4.4 volts) is somewhat larger than the inherent potential differences, the question of whether or not the experimentally applied current is of the same order of magnitude as the inherent bioelectric currents arises. Additional data are needed before a definite statement can be made in this connection, but attention should be directed to the fact that a very high resistance of the coleoptile epidermis must be taken into consideration. The reader should also recall that the inherent currents are continually in operation while the applied current was used for only 10 minutes.

The significance of the present experiments is to a large extent dependent on the fact that the induced curvature is actually a result of growth phenomena. Since it is known that the turgidity of some plant cells can be decreased by applied direct current, the possibility of inducing a sort of "osmotic" curvature in the coleoptile must be eliminated. Several reasons, which indicate that the curvature induced by transversely applied current is very likely *not* due to turgor changes, were given in an earlier paper (**11**). Furthermore, it can be shown by marking experiments that both sides of the coleoptile continue to elongate after the current has been applied. The side to which the electronegative contact was applied elongates more rapidly than the opposite side. In a typical experiment of this kind it was found that in the apical 20 millimeters (10 μamperes applied transversely for 10 minutes

5 millimeters below the apex) the electronegative side elongates 1.50 millimeters while the electropositive side elongates 1.05 millimeters in the same time. These facts, in addition to those previously mentioned (**11**), prove that the curvature which is being studied is due to growth phenomena and *not* to turgor changes.

The curves in figure 5 demonstrate a difference in the electrical responses when the current is applied at various levels below the apex. Maximum electrical response is obtained in the regions of the coleoptile which are actively elongating (**1, 14**) (see also figure 7A). This suggests a possible relation between the two phenomena. Examination of the curves in figure 5 in the light of THIMANN's data (**12**) indicates that the magnitude and the time course of the electrical changes, which are induced by the applied current, are *not* dependent on the distribution of growth hormones.

Summary

1. Ten μamperes of direct current applied transversely for 10 minutes to any level below the apex of the Avena coleoptile establishes a transverse electrical polarity and causes the coleoptile to bend.

2. The initial bending, in and above the contact region, is toward the electropositive pole of the current applying circuit. This is followed by a second bending which is basal to the contacts and toward the negative side of the coleoptile.

3. As the distance between the apex and the current applying contacts is increased, the amount of curvature induced by the given current decreases, but the time required to attain the maximum curvature in the initial direction increases.

4. A given quantity of current induces maximum electrical polarity when it is applied to levels more than 5 millimeters below the apex.

5. The curvature which was studied is due to growth phenomena and not to turgor changes.

6. The magnitude of the transverse electrical polarity and the time course of the electrical changes are not dependent on the distribution of the growth hormones.

The technical assistance of MISS JO-RUTH GRAHAM during this investigation is acknowledged with pleasure.

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RELATION OF WATER TO THE GERMINATION OF CORN AND COTTON SEEDS

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(WITH SIX FIGURES)

Received November 1, 1947

Introduction

The relation of plants to climatic conditions constitutes an extremely intricate complex of simultaneous variables and, despite extensive studies, remains one of the most inaccurately documented fields of plant science. This is unfortunate, particularly in relating the results of laboratory studies to the problems of the field. In this realm of plant science, water relations are perhaps most accurately known, many studies such as those of BRIGGS and SHANTZ (**2, 3**) having reported acceptable quantitative data. It is surprising that almost no studies have been reported on the environmental water relation of seeds and their significance. Ecologists have accepted classification of plants as hydrophytes, mesophytes, and xerophytes, but no one has shown whether or not seeds display comparable or related characteristics.

In the establishment of plants in their habitat, germination is an essential and active phase which is escaped only by those species which depend partly or completely upon vegetative production. It is obvious that hydrophytes, mesophytes, or xerophytes must produce seeds capable of germination in the habitat. Since the process of germination is of limited duration, the process may be accomplished during temporary periods of favorable water supply, or may take place under the less favorable condition average for the habitat. Such studies as have a bearing on the water relations have been concerned with the permeability of the seed coats, the gross absorption and water content, and the power with which the water is absorbed. Germination has been considered largely in relation to seed viability under conditions of favorable moisture and oxygen supply. While activities such as respiration and food transformation in seeds have been related to water content, the ultimate criterion of activity, namely, germination, has not been subject to quantitative studies.

A study was undertaken by the writer in 1941, and continued through 1942 and 1943, of the quantitative aspects of water absorption for germination. Seeds of widely different types of plants were selected for study to determine whether seeds actually differ in the total amount and rapidity of water intake for germination and to note the part played by the various anatomical structures in this process.

Seeds of sufficient size to permit quick dissection were selected from plants which represented hydrophytes, mesophytes, and xerophytes. These

were exposed to various conditions of moisture and the water content determined at 24-hour intervals.

Seed structure, though widely different in the various plant groups, has not been correlated with behavior or ecesis. Yet the fact is obvious that the success of a species may be critically dependent upon a successful germination under the conditions of the habitat. It is also apparent that differences in germination-water requirements, structure, and rate of water absorption may be of applied interest. In those seasons, and in those regions characterized by dry spring conditions, the advantage of germination in soil with limited water content might mean earlier crops, as well as better and more regular stands. If strains could be found with low germination-water requirements, crops might be possible in many parts of the Southwest where their production is not now practicable.

A study of the gross structure of seeds from plants of various ecological types, and the relation of the structures and the whole to germination water thus seemed important. This paper is devoted to the studies of water intake in relation to the germination behavior of corn and cotton seeds.

Water as a factor in germination

The necessity of water for the germination of seeds has long been taken for granted; but the amount of water necessary for germination, and the methods by which seeds absorb and distribute moisture have been given comparatively little notice.

Very little literature is available on the total amount of water necessary for germination. DETMER (**8**) found that the quantity of water absorbed by different kinds of seeds, when thoroughly soaked, was by no means the same; therefore, the capacity for absorbing water is different for different kinds of seeds. He found that the peas took up about 100% of their air dry weight, and wheat only 40 to 60%.

PETERS (**9**) worked on germination of seeds in a medium of low water content. He attempted to answer the question as to whether seeds can germinate when the amount of soil moisture is so low that plants growing in it will wilt and die. He found that seeds of peas, soybeans, and grains of corn and wheat germinated at or below the wilting coefficient of 1.31% moisture in quartz sand of 0.1-mm. size. Thus, his work substantiated the idea that seed can germinate in soil at or below the wilting coefficient of plants growing in soil of the same moisture content.

The rate of water absorption is so dependent upon temperature that the two factors, water and temperature, cannot be separated. BROWN and WORLEY (**7**) studied the effects of temperature upon the rate of water absorption by barley seeds, and claimed that the velocity of water absorption was almost an exponential function of the temperature. SHULL (**14**) attacked this same problem, using seeds of Xanthium and pea seed cotyledons, but could not find support for the BROWN-WORLEY theory in his data. The velocity of water intake at any given moment was found to be approximately an inverse exponential function of the amount of water previously absorbed.

A later study by SHULL and SHULL (**15**) on grains of corn, agreed satisfactorily with the earlier work on Xanthium and pea cotyledons. The rate of absorption at 55° was somewhat more than 8 times as great as at 5° C., whereas the chemical theory of water simplification by rising temperature would call for a rate thirty-two times as great at 55° as at 5°. The results with corn seeds were in complete agreement with the postulate that the rate of water intake depends upon the previous absorption, as an inverse exponential function.

Since one function of the seed coat is to serve as a vehicle for the conveyance of water, its structure and permeability are of importance. BROWN (**5**) reported semipermeability in barley (*Hordeum vulgare* var. *coerulescens*), and traced the semipermeability to the spermoderm of the grain, which resisted the action of 36% sulphuric acid. SCHRÖDER (**10**) found similar conditions in wheat and TJEBBES (**16**) obtained evidence of selective permeability in the seeds of sugar beets. SHULL (**11**) found that seeds of Xanthium have coats that are selectively permeable. In this case the middle and inner layers of the seed coat are mainly responsible for the observed phenomena. ATKINS (**1**) failed to find selective permeability in beans.

SHULL (**12**) made use of the almost perfect semipermeability of Xanthium seed coats toward the chlorides of sodium and lithium to measure the internal forces of seeds. Seeds were placed in solutions of these salts of varying concentrations and allowed to come to moisture equilibrium, which was indicated by constancy in the weight of the seeds. The osmotic concentration of the external solutions was known in each case from the vapor pressure of the solution. At equilibrium it was assumed that the internal forces and the external forces were equal. While the forces thus measured were by no means as large as those indicated for oven-dried material, still they were of considerable magnitude. In saturated solutions of sodium chloride, the seeds were able to crystallize salt out of solution by withdrawal of pure water from its hydration compounds. Air-dry seeds (moisture 7% above the absolute weight) had an initial imbibition pressure of little less than a thousand atmospheres (965), or more than 14,000 pounds per square inch. When the moisture content had been doubled (14% above absolute weight), the internal pressures had fallen to a little less than 400 atmospheres. He measured these forces across the entire range from air-dry to complete saturation.

Using seeds which had been calibrated in this manner SHULL (**13**) proceeded to measure the water-holding power of soils, and showed that air-dry soils and air-dry seeds were in equilibrium, at about 1000 atmospheres each. If the soil moisture were increased above air-dry, the seeds would absorb moisture until in equilibrium with the soil. For instance, at 3.5% above air-dry, the seeds and soil reached an equilibrium indicating about 375 atmospheres. When the soil moisture reached 6% above air-dry (Oswego silt loam subsoil) the moisture was held on the soil particles with about

130 atmospheres pressure. At 11%, soil moisture equilibrium indicated 22.4 atmospheres; and at the wilting coefficient (13.3%) the balance was equivalent to the action of 0.1 M sodium chloride solution, or about 4 atmospheres. Various soil types with differing wilting coefficients all gave similar results except the coarser sands. These studies have thrown much light upon the behavior of seeds with respect to the absorption of water, and have clarified the dynamics of water intake.

Finally, there are hard seeded species whose seed coats are impervious to water. Among these are certain legumes, clover, sweet clover, Kentucky coffee bean, morning glory, asparagus, okra, rose mallows, etc. The causes of hardness are still obscure, and most probably concern the chemical nature of certain cell layers within the testa. In some cases the outer layer of cells can be removed, notably in the rose mallows, and the seeds still remain hard. Such seeds may lie in water for months without absorbing appreciable amounts of moisture.

Materials and methods

A quantitative study of the course of water absorption by seeds during germination was made in order to determine (1) whether seeds actually differ in the total amount and rate of water intake; (2) to note the role played by the various parts of the seed; (3) to determine whether there exist seeds with "mesic," "hydric," or "xeric" germination modifications; and (4) to determine whether there are varietal differences in water absorption by seeds. Many types of seeds have been studied but, for the purposes of this report, the data are given only for the seeds of corn and cotton. The varieties of corn used are: Yellow Dent, "Sure Cropper," and Gehu Flint. Varieties of cotton used (*Gossypium hirsutum*) are Rogers Acala, 1940; Rogers Acala, 1941; and Drought Resistant #293.

For the experiments, seeds of each variety were selected for uniform size and appearance. Preparatory to germination they were sterilized by placing them in 0.01% $HgCl_2$ solution for 3 to 5 minutes and then rinsing twice in sterile distilled water. Forty seeds of each variety were then placed on filter paper in a sterilized Petri dish. Ten cc. of sterile distilled water were added to each dish and small quantities thereafter as needed. Practically no contamination occurred after this treatment. The seeds were allowed to germinate in the Petri dishes at room temperatures (25° to 30° C.). The cotton seeds were delinted by placing them in concentrated H_2SO_4 for 3 minutes to increase permeability of the seed coats.

At 24-hour intervals (0, 24, 48, 72, 96 hours) of germination, seeds were dissected into seed coats, cotyledons, "growing parts" of the embryo, and endosperm. The axis is hereafter referrred to as the "growing parts" of the embryo and as "embryo" in the tables and graphs because it is the part of the seed that develops into the mature plant. The percentage of water was determined on similar parts of 20 seeds of each kind and expressed on the absolute basis. The amount and percentage of water absorbed by the entire seed were determined by the same methods.

At each interval of germination time a new set of 20 seeds was selected. The amount of hygroscopic water present in the parts of air-dry seeds was determined by dissecting the seeds into their parts and determining the moisture content. The percentage of hygroscopic water was calculated on the absolute basis for each part and for the seed as a whole.

The Dent corn was dissected dry but, because of the difficulty encountered with it, the other varieties of corn and the cotton seeds were soaked in water long enough to make dissection possible. After dissection, the parts were air-dried to constant weight before the hygroscopic moisture determinations were made. It required about ten days of clear weather to return to air-dry condition after soaking and dissection. The period of soaking, before desiccation, was only three hours.

Observations and results

Corn

Pericarp and integuments.—The protective covering of the grain of corn, sometimes called the hull, consists of the pericarp and the testa. The

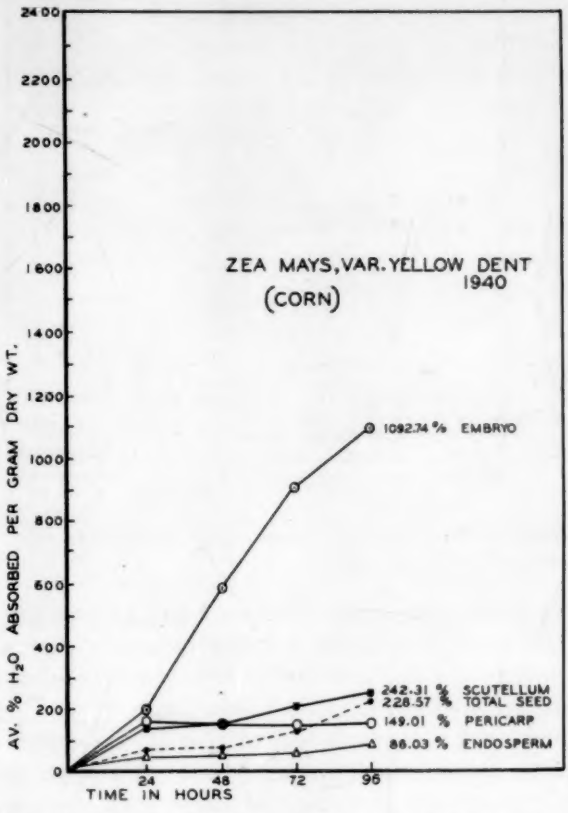

Fig. 1. Absorption of water by the various organs of *Zea mays*, var. Yellow Dent (1940), during early phases of germination.

cells of the pericarp continue to divide and increase in size and, as the fruit nears maturity, these cells cease to divide and the walls thicken. The subsequent increase in size of the pericarp is due to the stretching of tissues already formed. Its late development, at all stages, causes it to be in a constant state of tension and gives it a tough fibrous texture in the mature form. The translucent hull shows little or no starch but scattered traces of reducing sugar.

During germination the hull transfers water to the interior of the grain,

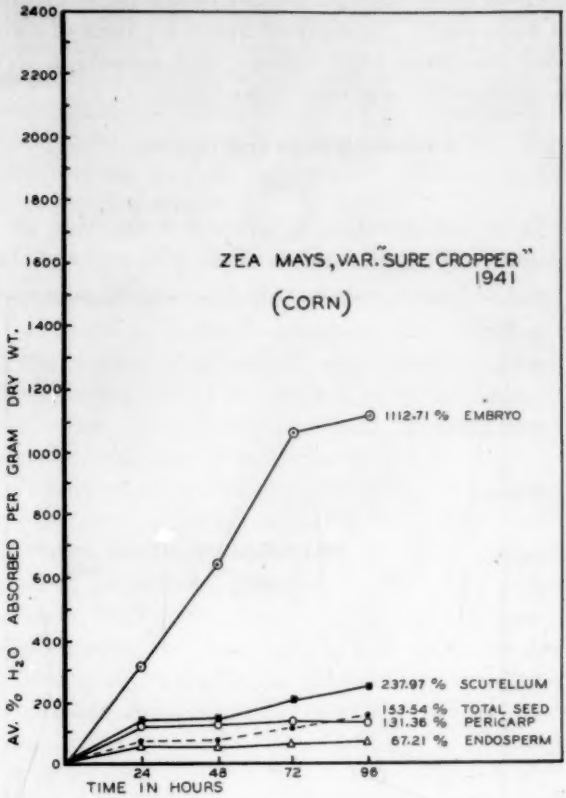

FIG. 2. Absorption of water by the various organs of *Zea mays*, var. "Sure Cropper" (1931), during early phases of germination.

and of course retains some water. Tables I and II give the weights and percentage relations of water in the hull of germinating grains and figure 1 shows the percentage of water absorbed by this structure in comparison with its own dry weight, as exemplified by Yellow Dent.

It will be seen that a water content of 155.56% is reached in 24 hours, after which there is maintained a slightly lower but approximately stable water content throughout the period of observation. Computed as percentage of water in the germinating seeds (table II, column c) the hull at-

TABLE I

WATER ABSORBED BY GERMINATING SEED OF CORN AND COTTON

PLANT	TIME	TOTAL			PARTS OF SEED											
					EMBRYO			SCUTELLUM OR COTYLEDON			ENDOSPERM			PERICARP OR SEEDCOAT		
		a*	b†	c‡	a	b	c	a	b	c	a	b	c	a	b	c
	hrs.	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%
Corn, 1940	0	0.0575	12.98	100	0.0006	10.52	1.04	0.0041	9.27	7.13	0.0493	13.80	85.73	0.0034	9.67	5.91
	24	0.3185	64.36	100	0.0118	187.12	3.70	0.0747	143.88	23.45	0.1888	46.20	59.27	0.0432	155.43	13.56
	48	0.3577	76.76	100	0.0557	576.08	15.57	0.0705	148.39	19.70	0.1885	49.71	52.69	0.0430	145.09	12.02
	72	0.5608	132.54	100	0.2078	905.29	37.05	0.0917	205.45	16.35	0.2148	50.77	38.30	0.0465	142.34	8.29
	96	0.8383	228.57	100	0.4782	1092.74	57.04	0.1036	242.31	12.35	0.2203	86.03	26.27	0.0362	149.01	4.31
Cotton, 1940	0	0.0075	6.91	100	0.0003	6.49	4.00	0.0033	5.29	44.00	0.0004	7.50	5.33	0.0036	9.54	48.00
	24	0.1240	119.87	100	0.0119	275.09	9.59	0.0770	126.12	62.09	0.0069	199.15	5.56	0.0299	83.15	24.11
	48	0.1947	198.55	100	0.0499	736.05	25.62	0.1111	208.83	57.06	0.0087	326.22	4.46	0.0299	82.87	15.35
	72	0.2864	286.88	100	0.0937	868.55	32.71	0.1543	301.37	53.87	0.0124	455.84	4.32	0.0286	80.47	9.98
	96	0.3108	301.14	100	0.1185	1067.95	38.12	0.1478	296.26	47.55	0.0149	389.66	4.79	0.0297	77.44	9.55
Cotton, 1941	0	0.0123	12.55	100	0.0003	7.49	2.42	0.0080	15.62	65.04	0.0004	8.17	3.25	0.0035	9.48	28.45
	24	0.1226	115.9	100	0.0095	203.03	7.74	0.0726	124.86	59.21	0.0082	209.63	6.68	0.0324	82.92	26.42
	48	0.1561	147.36	100	0.0235	452.22	15.05	0.0939	160.82	60.15	0.0083	230.33	5.31	0.0304	78.79	19.47
	72	0.2669	256.21	100	0.0813	988.66	30.45	0.1428	276.98	53.50	0.0107	289.27	4.00	0.0320	83.24	11.98
	96	0.3323	320.53	100	0.1442	1198.64	43.39	0.1447	301.22	43.54	0.0136	308.34	4.09	0.0299	76.37	8.99

* a—Grams water per seed.
† b—Percentage water of part to its dry weight.
‡ c—Percentage water of part to total water in seed.

TABLE II

WATER ABSORBED BY GERMINATING SEED OF 3 VARIETIES OF CORN

PLANT	TIME	TOTAL			PARTS OF SEED											
					EMBRYO			SCUTELLUM OR COTYLEDON			ENDOSPERM			PERICARP OR SEEDCOAT		
		a*	b†	c‡	a	b	c	a	b	c	a	b	c	a	b	c
	hrs.	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%
Corn: Yellow Dent, 1940	0	0.0575	12.98	100	0.0006	10.52	1.04	0.0041	9.27	7.13	0.0493	13.80	85.73	0.0034	9.67	5.91
	24	0.3185	64.36	100	0.0118	187.12	3.70	0.0747	143.88	23.45	0.1888	46.20	59.27	0.0432	155.43	13.56
	48	0.3577	76.76	100	0.0557	576.08	15.57	0.0705	148.39	19.70	0.1885	49.71	52.69	0.0430	145.09	12.02
	72	0.5608	132.54	100	0.2078	905.29	37.05	0.0917	205.45	16.35	0.2148	50.77	38.30	0.0465	142.34	8.29
	96	0.8383	228.57	100	0.4782	1092.74	57.04	0.1036	242.31	12.35	0.2203	86.03	26.27	0.0362	149.01	4.31
Corn: Sure Cropper, White Dent, 1941	0	0.0380	10.80	100	0.0003	8.51	0.78	0.0029	7.23	7.63	0.0333	11.69	87.63	0.0016	6.35	4.21
	24	0.3147	75.85	100	0.0145	318.57	4.60	0.0700	162.79	22.24	0.1981	58.11	62.94	0.0321	121.65	10.19
	48	0.3400	83.23	100	0.0481	645.21	14.14	0.0766	184.26	22.52	0.1837	55.08	54.02	0.0316	121.44	9.29
	72	0.4410	117.21	100	0.1378	1062.26	31.24	0.0847	242.21	19.20	0.1853	61.36	42.01	0.0333	126.25	7.55
	96	0.6554	153.54	100	0.2969	1112.71	45.30	0.1002	237.97	15.28	0.2220	67.21	33.87	0.0362	131.36	5.52
Corn, Gehu Flint, 1941	0	0.0299	10.38	100	0.0002	5.67	0.66	0.0024	7.30	8.02	0.0262	11.29	86.62	0.0012	5.62	4.01
	24	0.2272	71.21	100	0.0165	374.03	7.26	0.0473	143.33	20.81	0.1399	53.34	61.57	0.0235	121.11	10.34
	48	0.2677	83.43	100	0.0529	717.75	19.76	0.0518	162.84	19.35	0.1423	54.07	53.15	0.0207	112.26	7.73
	72	0.3996	132.48	100	0.1691	1055.68	42.31	0.0610	182.56	15.26	0.1440	62.05	36.03	0.0255	127.22	6.38
	96	0.5366	178.00	100	0.2939	1102.80	54.77	0.0631	187.61	11.75	0.1560	70.03	29.07	0.0236	127.97	4.39

* a—Grams water per seed.
† b—Percentage water of part to its dry weight.
‡ e—Percentage water of part to total water in seed.

tained a maximum of 13.5%. This percentage of total seed water in the hull decreases after 24 to 48 hours, as hydration of the grain continues. The above observations apply to all varieties of corn used (table II).

The varieties of corn used show different maximum water content at saturation. In order of decreasing water content at the saturation point the varieties are Yellow Dent, "Sure Cropper," and Gehu Flint (table II, and figs. 1, 2, and 3). The dry weight of the pericarp decreased in the same order; therefore the percentage of water content is comparatively constant.

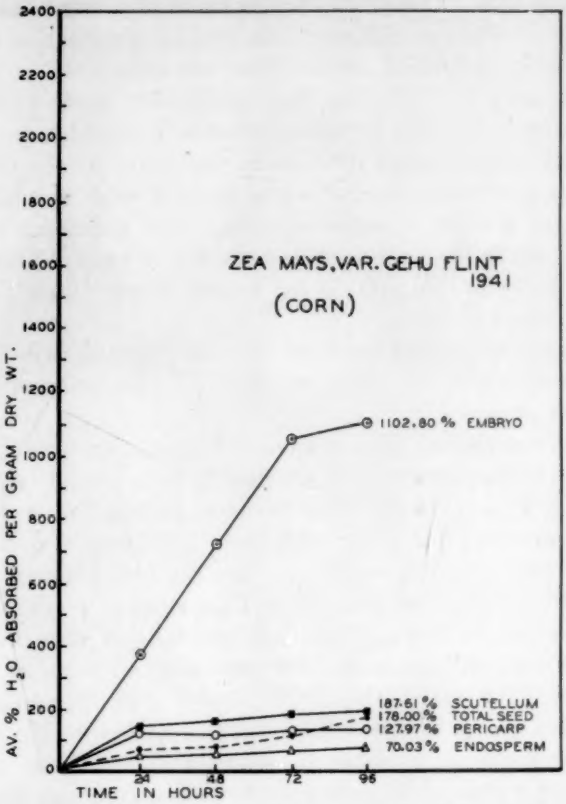

FIG. 3. Absorption of water by the various organs of *Zea mays*, var. Gehu Flint (1941), during early phases of germination.

The hull absorbs water imbibitionally to maximum hydration in 24 hours. After that, it permits the passage of water to the rest of the grain. SHULLS's measurements of the rate of water absorption (**14**) were probably made while the seed coat was becoming hydrated. His curves (fig. 1) indicate that Xanthium seeds reached the relatively stable stage after 12–18 hours. That the Gramineae behave in an essentially different manner as suggested by SHULL (**11**) in reference to the work of BROWN (**6**) is not borne out by the writer's results; however, his statement bears out the report of BROWN for the one variety *coerulescens*, of *Hordeum vulgare*.

The three varieties of corn used show very similar behavior of the hull in relation to water, the chief difference being that "Sure Cropper" and Gehu Flint reached the maximum water content at lower percentages than Yellow Dent.

It may be noted in table II that the stable water content of the hull of Yellow Dent tended to decrease after the 24-hour maximum, while that of "Sure Cropper" and Gehu Flint tended to increase slightly throughout the period of observation.

ENDOSPERM AND SCUTELLUM.—Tables I and II present data on water relations of the endosperm and scutellum during germination and figures 1, 2, and 3 show the hydration curves of the two structures.

From the data it is obvious that moderately rapid hydration of endosperm occurs in the first 24 hours, which is followed by continuous slow increase in water absorption throughout the period of observation. Maximum amount and percentage of water content were reached at the final 96-hour period for all varieties of corn. The maximum percentage of moisture was about the same as that occurring in the hull, the comparative percentages being 57, 51, and 50 for Yellow Dent, "Sure Cropper," and Gehu Flint, respectively.

The percentage of water based on the total water absorbed by the grains of corn decreased after 24 hours, owing to the absorption of the "growing parts" of the embryo.

Different varieties of corn showed different maximum percentages of water content in the endosperm at the final 96-hour period (table II, column b, and figs. 1, 2, 3). Of the three varieties tested, Yellow Dent absorbed the highest percentage of water with Gehu Flint second and "Sure Cropper" the lowest (table II, column b); but the percentage of water to the total water absorbed by the seed (table II, column c) was highest in "Sure Cropper," second in Gehu Flint, and lowest in Yellow Dent. The endosperm is a non-active mass of food materials and contains 85% or more of the total seed water in the air-dry state. This percentage decreased throughout the period of observation to 26 to 34% with the growth of the embryo. Since column a, table II, shows a slow increase in the actual amount of water present in grams in the endosperm, this decreasing relative percentage resulted from the much greater absorptive activity of the growing embryo and scutellum.

The amount of water in Gehu Flint was the lowest observed (table II, column a), and the total percentage of germination water was least in the endosperm of Yellow Dent, because of the high values of the embryo, including the scutellum. The Flint differed from the varieties of Dent studied by its lower percentage of water in the hull and endosperm.

In order to determine the storage functions of the cotyledons as compared to that of the endosperm, the data were tabulated in table IV, which shows the percentage proportions of the dry weights of the endosperm and cotyledons. The dry weights of the seed coats remained approximately constant; those of the embryos increased with growth (table IV).

TABLE III

WATER ABSORBED BY GERMINATING SEED. COTTON: ROGERS ACALA, 1941 AND DROUGHT RESISTANT #293, 1941

PLANT	TIME	TOTAL			PARTS OF SEED											
					EMBRYO			COTYLEDON			ENDOSPERM			SEEDCOAT		
		a*	b†	c‡	a	b	c	a	b	c	a	b	c	a	b	c
	hrs.	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%
Cotton:	0	0.0123	12.55	100	0.0003	7.49	2.42	0.0080	15.62	65.04	0.0004	8.17	3.25	0.0035	9.48	28.45
Gossypium	24	0.1226	115.90	100	0.0095	203.03	7.74	0.0726	124.86	59.21	0.0082	209.63	6.68	0.0324	82.92	26.42
hirsutum,	48	0.1561	147.36	100	0.0235	452.22	15.05	0.0939	160.82	60.15	0.0083	230.33	5.31	0.0304	78.79	19.47
var. Rogers	72	0.2669	258.21	100	0.0813	988.66	30.45	0.1428	276.98	53.50	0.0107	289.27	4.00	0.0320	83.24	11.98
Acala, 1941	96	0.3323	320.53	100	0.1442	1198.64	43.39	0.1447	301.22	43.54	0.0136	308.34	4.09	0.0299	76.37	8.99
Cotton:	0	0.0084	7.60	100	0.0003	7.59	3.57	0.0037	6.21	44.04	0.0003	5.46	3.57	0.0041	9.84	48.80
Gossypium	24	0.1193	108.98	100	0.0082	174.83	6.87	0.0724	118.16	60.68	0.0089	256.63	7.46	0.0298	74.42	24.97
hirsutum,	48	0.1382	131.38	100	0.0111	233.91	8.03	0.0831	144.89	60.13	0.0118	270.18	8.53	0.0321	63.12	23.22
var. Drought	72	0.1540	141.61	100	0.0161	345.03	10.45	0.0949	158.53	61.62	0.0121	294.04	7.85	0.0310	78.91	20.12
Resistant (#293) 1941	96	0.1863	169.04	100	0.0295	557.49	15.83	0.1109	181.66	59.52	0.0125	302.49	6.70	0.0334	84.05	17.92

* a—Grams water per seed.
† b—Percentage water of part to its dry weight.
‡ c—Percentage water of part to total water in seed.

TABLE IV

RELATION OF SEED ORGANS TO TOTAL DRY SEED

NAME	TOTAL DRY WEIGHT OF SEED	EMBRYO			COTYLEDONS OR SCUTELLUM			ENDOSPERM		
		DRY WT.	% OF TOTAL DRY SEED	% OF GAIN IN DRY WT. AT 96 HRS.	DRY WT.	% OF TOTAL DRY SEED	% LOSS IN DRY WT. AT 96 HRS.	DRY WT.	% OF TOTAL DRY SEED	% LOSS IN AIR DRY SEED AT 96 HRS.
	gm.	*gm.*	%	%	*gm.*	%	%	*gm.*	%	%
Yellow Dent Corn	8.8516	0.1160	1.31	654.40	0.8893	10.04	3.83	7.1491	80.77	28.38
Sure Cropper Corn	7.0298	0.0669	0.95	697.40	0.7896	11.23	0.00	5.1973	73.93	0.00
Gehu Flint Corn	5.7568	0.0605	1.06	766.60	0.6464	11.22	0.00	4.6450	80.68	3.99
Rogers Acala Cotton, 1940	2.1622	0.0885	4.09	150.60	1.2295	56.80	18.77	0.0946	4.37	29.50
Rogers Acala Cotton, 1941	1.9532	0.0874	4.50	170.90	1.0253	52.49	6.02	0.1027	5.25	28.20
Drought Resistant cotton, 1941	2.2048	0.0855	3.80	22.30	1.1791	53.47	0.00	0.1037	4.70	20.04

The endosperm decreased in dry weight during the observation period; 28% in Yellow Dent and 4% in Gehu Flint. No reduction was found in "Sure Cropper," probably because the loss in weight was small and obscured by variation due to the method used.

In summary, the results obtained in these experiments show that the endosperm of "Sure Cropper" and Gehu Flint exhibit a small decrease in dry weight during the period of observation, Yellow Dent showing the greater decrease. In comparison to this, the decrease in dry weight of the scutellum appears low; it is obviously only a secondary storage organ. No

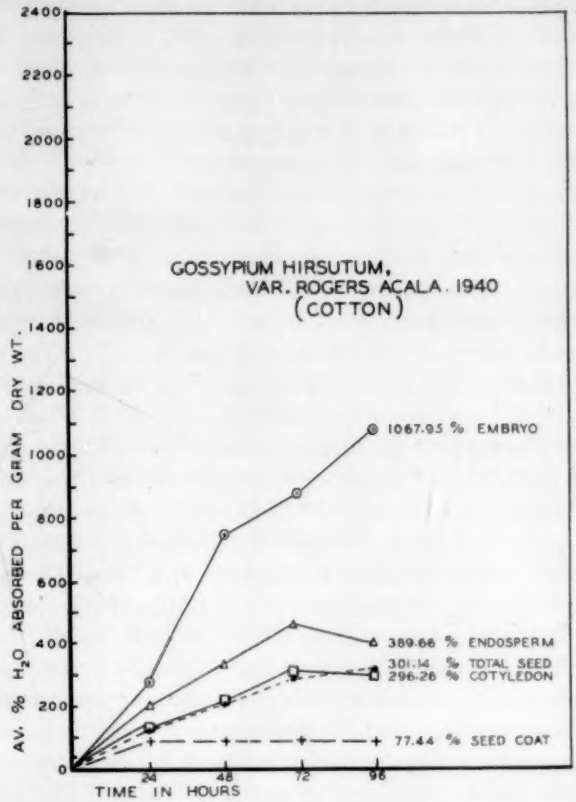

FIG. 4. Absorption of water by the various organs of the seed of *Gossypium hirsutum* var. Rogers Acala (1940), during the early phases of germination.

varietal differences in the corn used are obvious, other than that to be expected from the greater rate of activity of the embryo of Yellow Dent.

The large endosperm acts not only as a food supply but also as a reservoir for absorbed water; the scutellum also contains a considerable amount of water, approximating that found in other parts of the embryo.

THE EMBRYO.—For the study of the "growing parts" of the embryo behavior in relation to germination water, the same varieties of corn and cotton were used as for the study of seed and fruit coats, and "food storage"

organs. The results are recorded in tables I, II, and III, and in the curves of figures 1 to 6. Tables I and II give the weights and percentage relations of water in the "growing parts" of the embryo of germinating kernels of corn, and the curve in figure 1 shows the percentage of germination water absorbed by this structure, as exemplified by the variety Yellow Dent.

It will be seen that a high percentage of water is absorbed in the first 24 hours, after which there is maintained a continuous high rate of absorption throughout the period of observation (table I, column b, and fig. 1). This percentage of moisture content is higher than that of any other part of the kernel. The percentage of total seed water in the "growing parts" of the embryo increases throughout germination, until a maximum is reached at the final reading (table II, column c). The amount of water in the grains also increases throughout germination (table II, column a).

The dry weight of the embryo is less than 2% of the total dry weight of the seed. This increased during germination.

The observations here recorded are true for all varieties of corn tested (table II).

The varieties of corn do differ, however, in their capacity for early absorption of water. This is shown by the fact that "Sure Cropper" absorbed the highest percentage, Gehu Flint second, and Yellow Dent the lowest in the first 24 hours (table II, column b, and figs. 1, 2, 3). The final reading shows less difference in the maximum percentage of water content for the three varieties; all three are very high.

The rate of absorption and percentage of total seed water in the "growing parts" of the embryo were different for the different varieties (table II, column c), the maximum being reached at the final reading. Of the three varieties tested, Yellow Dent absorbed the highest percentage of the total-germination water, Gehu Flint second highest, and "Sure Cropper" least.

The "growing parts" of the embryo is of course the growing part of the grain. This is evidenced by the consistent increase in the dry weight of the embryo during germination, and the increase in size and rapid increase in amount and percentage of water in proportion to other parts of the seed. Although the growth of the embryo is partly due to an increase of absorbed materials at the expense of stored food, much of the increase in size is due to hydration, as shown by the data (tables I and II, columns a, b, c).

The growing part of the embryos of all varieties reached similar water content at the final 96-hour reading. In the air-dry grains, this organ of all varieties contained a very small proportion of the seed moisture (1% or less), compared to that of the endosperm (85% or more), as shown in table II, column c.

Varietal differences appear in the air-dry water content, which was high (10.52%) in Yellow Dent, and low (5.67%) in Gehu Flint. In rate of water absorption, the "growing parts" of the embryo of Gehu Flint reached a water content of 374.4% in 24 hours, while in Yellow Dent the water con-

tent was 187.12%. "Sure Cropper" White Dent showed intermediate values.

While the "growing parts" of the embryo reached a final water content which was similar in all varieties tested, that of Gehu Flint may be considered to show a comparative adaptation to germination in dry land conditions. This was shown by its rapid initial absorption of water.

Cotton

Seed coat.—Tables I and III give weights and percentage relations of water in the seed coats of cotton and figure 4 shows the typical hydration curves as found in the seed coats of Rogers Acala cotton seeds.

These data show that, as in corn, maximum hydration occurs in 24 hours and approximate stability is thereafter retained. It is striking that complete hydration is reached in the seed coats of cotton at about 80% water content, compared with 155% in corn. Column c, tables I and III, shows that the percentage of the total seed water contained in the seed coats is greater in the air-dry condition than at any succeeding period in germination. This was not true in corn. The seed coats of cotton are obviously more hygroscopic than the hull of corn, or than any organ in either corn or cotton except the food supply. Air-dry seeds of cotton thus contain a considerable portion of their water content in the seed coat. Progressive decrease in percentage of germination water in the seed coat in the course of the hydration of the inner seed, appears as in corn.

All varieties used behaved similarly (table III), but small varietal differences appear in Drought Resistant #293, in which the seed coat reached its maximum hydration only at 96 hours, and thus maintained a higher percentage of germination-water (table III, column c, and fig. 6). The seed coats in this variety are obviously more hygroscopic than is the case in Rogers Acala.

A year of storage under laboratory conditions showed mainly the progressive drying of the "growing parts" of the embryo. The higher proportional percentage of water in seed coats of air-dry seeds of the 1940 cotton (table I, column c and curves of fig. 4), obviously resulted from this slight drying out of the endosperm and of the "growing parts" of the embryo during storage and from the marked desiccation of the cotyledons as compared to the constant water content exhibited by the seed coats. Thus, table I shows that during a year's storage the endosperm and "growing parts" of the embryo decrease in water content 1% or less, while the cotyledons decreased from 15.62 to 6.29%

Cotyledons and endosperm.—Tables I and III give the data on the behavior of the food storage tissues of cotton seeds and figure 5 shows the curves for percentage of water content for variety Rogers Acala, 1941. This food is stored in the cotyledons and small portions of the endosperm. The plotted data for Rogers Acala and Drought Resistant #293 are shown in figures 5 and 6.

The amount of water absorbed, expressed as percentage of water content, (table III, column b) was large the first 24 hours in both cotyledons and endosperm, and in both cases continued to increase rapidly throughout the period of observation.

As in the endosperm of corn, the final amount (column a) and percentage value (column b) was highest at the final 96-hour reading; although the absolute amount of water per seed was considerably less than that observed in the endosperm of corn, the percentage was very much greater (column b).

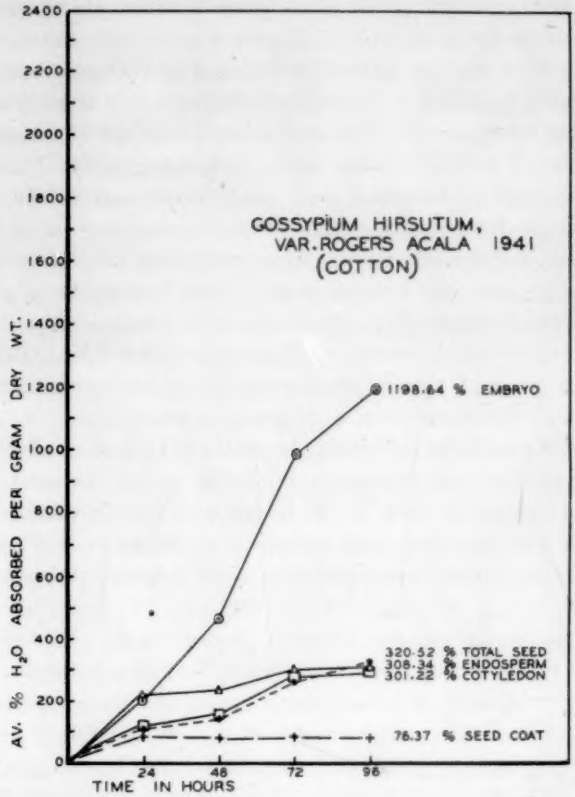

FIG. 5. Absorption of water by the various organs of the seed of *G. hirsutum* var. Rogers Acala (1941), during the early phases of germination.

The proportion of total-germination water held in the cotyledons of cotton was similar to that held in the endosperm of corn, but less variable. The proportion of the total germination water, as in other parts not actively growing, reached a maximum at the 24-hour period, and decreased slightly thereafter. The data show that in Rogers Acala the stored food supply in the cotyledons absorbed a larger quantity and a greater percentage of their own dry weight, and of the total amount of germination-water, than in variety Drought Resistant #293.

The stored food in cotton seeds, although contained chiefly in the cotyledons instead of in the endosperm as in corn, behaved similarly in showing continuous hydration in 96 hours. These cotyledons differ from the endosperm of corn in absorbing larger amounts of water. Tables I and III, and figures 4, 5, and 6 show that the endosperm of cotton absorbs water very rapidly in the first 24 hours, 300 and 257% respectively, for Rogers Acala, and Drought Resistant #293, as compared to corn 48, 199, and 209% in Yellow Dent, "Sure Cropper," and Gehu Flint, respectively. It continues to absorb water slowly throughout the observation period, reaching a maximum of 308% in Rogers Acala and 302% in Drought Resistant #293 at the final reading.

The percentage proportions of water in the seed increased at first and then decreased (column c), due to growth of the embryo. The dry weight of endosperm of cotton is about 5% of the total dry weight of the seed, while that of corn is about 80% (table IV). In spite of its small size in comparison to corn, this substance is initially more rapid in its absorption of water than is the endosperm of corn. The dry weight of the endosperm decreases very slightly throughout germination because of the rapid initial and slow continuous water absorption of the endosperm. In spite of its very small mass in comparison with other seeds used, it is obvious that cotton endosperm is an effective water absorbing and distributing agency; chemical tests and slight decrease in the weight of this structure during germination indicate that it serves only secondarily as a food storage organ.

From the results obtained it is obvious that the cotyledons of cotton are primarily food storage organs, and the scant endosperm is primarily a water absorbing substance.

THE EMBRYO.—Data on the "growing parts" of the embryo of cotton in relation to germination water are tabulated in tables I and III, and the percentage of water content absorbed is shown in figure 5 for Rogers Acala, 1941.

It is obvious that a high percentage of water is absorbed in the first 24-hour period of germination, after which there is a continuous high rate of absorption throughout germination (table I, column b). The percentage water content of the embryo was higher than that of any other part of the seed.

The percentage of total seed water absorbed by the "growing parts" of the embryo increased throughout germination until a maximum was reached at the final 96-hour period of observation (table I, column c). The amount of water in grams also increased throughout the period of observation (column a).

The dry weight of the "growing parts" of the embryo was between 3 and 5% of the total dry weight of the seed, that of the corn being less than than 2%. The dry weight of this growing part of the cotton seed increased during germination.

These observations hold for both varieties of cotton tested (Rogers Acala,

and Drought Resistant #293), as shown in table I and III, columns a, b, and c, and figures 4, 5, and 6.

The two varieties, however, showed different capacities for absorption of water during the first 24 hours (table III), the percentage of water content being more comparable to that of Yellow Dent corn than to the other varieties of corn tested. Rogers Acala absorbed a higher percentage than Drought Resistant (table III, column b). The final observation showed a great difference in the maximum percentage of water content for the two

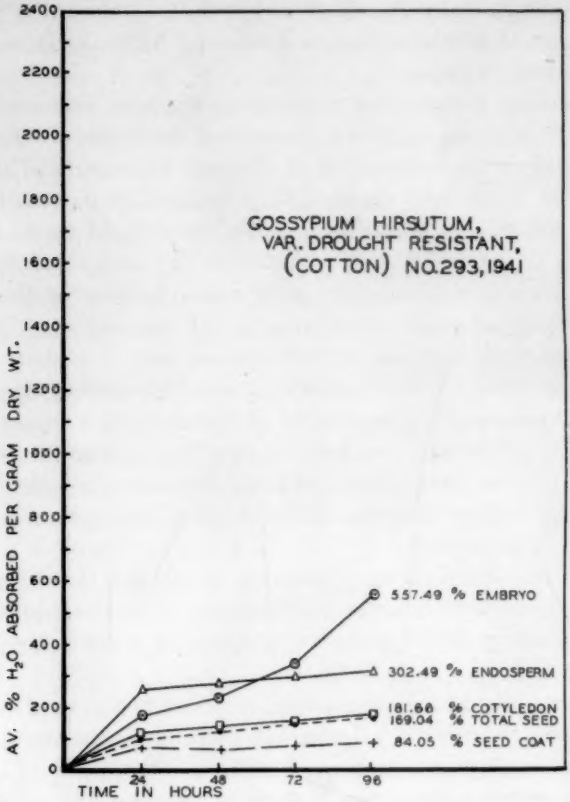

FIG. 6. Absorption of water by the various organs of the seed of *G. hirsutum* var. Drought Resistant #293 (1941), during the early phases of germination.

varieties, but both reached a high level in proportion to other parts of the seed. This high percentage of water content absorbed by Rogers Acala is similar to that of all varieties of corn.

The rate and percentage of total seed water in the "growing parts" of the embryo were different for the two varieties used (table III, column c), their highest values being reached at the final reading. Rogers Acala absorbed the higher percentage of total germination water, this final high percentage being more like that of the varieties of corn studied.

The "growing parts" of the embryo of cotton seed, like that of corn,

are the growing portion of the seed. This is evidenced by the consistent increase in the dry weight during germination, as well as by the increase in size and rapid increase in amount and percentage of water as compared with other parts of the seed. Also, like that of corn, the growth of the "growing parts" of the embryo is partly an increase in materials at the expense of the stored food, even though much of the increase in size is due to hydration, as shown by data in tables I and III, columns a, b, and c. The "growing parts" of the embryo of both varieties of cotton increased in size noticeably through hydration.

Even though the "growing parts" of the embryo of both varieties reached a high percentage of water content at the final reading in proportion to that of other parts of the seed, that of Rogers Acala absorbed more than twice as much as did that of Drought Resistant #293. This high maximum was preceded by a higher rate of water absorption in Rogers Acala than in Drought Resistant. In the air-dry seed, the "growing parts" of the embryo of both varieties contained a small proportion of the seed moisture (less than 4%) which was similar to that of the endosperm. The cotyledons and seed coats contained a much higher percentage in both the varieties. The percentage of moisture in the air-dry embryo of corn is less than 1% (table II, column c).

The percentage of water content in the embryos of the air-dry seed is almost the same for the two verieties of cotton (table II, column b) and most comparable to that of "Sure Cropper" corn. In Rogers Acala, the "growing parts" of the embryo reached 203.03% water content in the first 24 hours, compared to 174.83% for the same tissues of Drought Resistant. These values are most similar to that of the "growing parts" of the embryo of Yellow Dent corn (table II, column b).

While the growing embryo has reached a final percentage of water content which was different in the two varieties, Rogers Acala shows adaptation to dry land conditions by absorbing water rapidly the first 24 hours, and by continuing this rapid rate of absorption during germination; and Drought Resistant #293 shows adaptation by not requiring as great a quantity of water for germination. The comparatively low percentage of initial water absorption by Drought Resistant #293 may be due to a low capacity for absorbing water; the comparatively low maximum percentage of water content reached at the final reading may be due either to low absorbing power, or to a slow rate of absorption which causes the embryo to fail to reach its maximum equilibrium value at the final reading.

Summary and conclusions

This is a report on the germination water relations of three varieties of corn (Yellow Dent, Sure Cropper White Dent, and Gehu Flint), and two varieties of cotton, *Gossypium hirsutum* var. Rogers Acala, for 1940 and 1941; and var. Drought Resistant #293. The conclusions reached are as follows:

1. The seeds tested differ in percentage of initial 24-hour water intake and in percentage of final 96-hour water absorption. Rogers Acala cotton, 1940, absorbed 119.87% in the first 24 hours; same var., 1941, 115.90%; and var. Drought Resistant #293, 108.98%; Sure Cropper corn, 75.85%; Gehu Flint corn, 71.21%; and Yellow Dent corn, 64.36%. They are listed in a descending order of absorption rate, for the first 24 hours.

The total water absorption at the final 96-hour period of observation is for Rogers Acala cotton, 1941, 320.53%; same var., 1940, 301.14%; Yellow Dent corn, 228.57%; Gehu Flint corn, 178%; Drought Resistant #293 cotton, 169.04%; and Sure Cropper corn, 153.54%. It is obvious from these figures that not all seeds require the same percentage of water for germination.

2. Each part of the seed plays one or more roles in seed germination:

(a) The seed coats of all seeds behave similarly in that they absorb water quickly until an approximate saturation level is reached, and this saturation level is approximately maintained thereafter. The percentage of total seed moisture in these organs decreases after the saturation level is reached to the final 96-hour period of observation. This indicates that the seed coats serve as transporting agents for water from the external water supply to the internal parts of the seed. The seed coats absorb water passively by hygroscopic and imbibitional processes. Seed coats of different seeds have different hygroscopic and imbibitional absorption capacities throughout germination. These capacities are partly due to morphological differences of the seed coats, and partly to the activity of internal seed parts in rate and percentage of water absorption.

(b) The endosperm of the seeds of the three varieties of corn serves as a reservoir of primary importance for both food and water. The endosperm of the seeds of *Gossypium hirsutum* serves primarily as a water reservoir and only secondarily for food storage, the great power of absorption and storage of water in these seeds being due to the hydrophilic colloidal nature of the endosperm in comparison to that of other seeds.

(c) Not all cotyledons perform the same function. The scutellum (cotyledon) of the three varieties of corn digests starch into sugar and transports it and water from the endosperm to the "growing parts" of the embryo. The cotyledons of the seeds of *Gossypium hirsutum* var. Rogers Acala (both 1940 and 1941 crops), and of *G. hirsutum* var. Drought Resistant, are reservoirs of primary importance for both soluble food and water, and they transport both to the "growing parts" of the embryo to be used in growth.

(d) The axis of all seed used is the "growing parts" of the seed. This is evidenced by the consistent increase in the dry weight of the growing portion of the embryo, the amount of water absorbed, and the increase in total percentage of seed moisture throughout germination. It is further evidenced by the fact that the embryos of all seeds tested attained the highest maximum percentage of any seed organ at the final 96-hour period of observation.

3. Apparently seeds exist with mesic, hydric, or xeric germination adaptations or tendencies thereto.

Seeds of Rogers Acala cotton (both 1940 and 1941 crops), of Yellow Dent and "Sure Cropper" corn are adjusted to germination in mesic habitat.

Seeds of Drought Resistant cotton are adapted to germination in very dry land, or xeric habitat of temporary water after a rain.

Seeds of Gehu Flint corn are adapted to germination in dry-land conditions, tending toward xeric conditions.

4. Such adaptations of seeds for germination in mesic, hydric, or xeric conditions are evident in germination in the water requirements of the "growing parts" of the embryo, and in the imbibitional capacity of the cotyledons and endosperm to absorb and store water for use by the "growing parts" of the embryo as needed.

5. Varietal differences appear in the germination-water requirements of seeds of the three varieties of *Zea mays* and the two varieties of *Gossypium hirsutum*.

(a) The chief varietal difference in kernels of *Zea mays* lies in the different capacities of the embryos for early absorption of water. The embryo of Gehu Flint corn absorbs the highest percentage (374.03), that of "Sure Cropper" the second highest (318.57), and that of Yellow Dent the lowest (187.12) during the initial 24-hour period of germination. The final percentage of germination-water shows less difference.

(b) The chief varietal differences in the two varieties of cotton seed used apparently lie in the germination-water requirement of the embryo, the capacity rate of water absorption by the endosperm, the hygroscopicity of the seed coats, and the percentage of final germination-water absorbed by the seeds.

The embryo and seed of Drought Resistant cotton require about half the percentage of water required by Rogers Acala, 1941. Thus, a low percentage of water in the embryo of Drought Resistant cotton, the rapid initial and extended absorption of water, and the high percentage of water in the endosperm of this variety of cotton adapt this seed to germination in dry-land conditions; the seed of Rogers Acala, requiring twice as much water, is adapted to germination under more mesic conditions.

This investigation further indicates that various seeds do differ in the total amount of water absorption and the rate of its absorption; that different organs of the seed play different roles in the process of germination; that seeds apparently possess degrees of mesic, hydric, and xeric adaptations in germination; and that varietal differences appear in water absorbing capacity of seeds of the several varieties of corn and cotton tested.

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EFFECT OF NUTRIENT LEVEL ON THE GROWTH AND CHEMICAL COMPOSITION OF SWEETPOTATOES IN SAND CULTURES

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(WITH FIVE FIGURES)

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The present study was undertaken to determine the general nutrient requirements of the sweetpotato since field fertilizer tests have yielded a variety of responses with different fertilizer treatments. Sweetpotatoes usually respond to small applications of nitrogen fertilizers but excessive fertility often results in too much vine growth and few storage roots.

The study to be reported was conducted on the influence of three or more concentrations of the following chemicals upon vine growth, storage root production, and chemical composition of the sweetpotato plant: $NaNo_3$, NaH_2PO_4, $CaCl_2$, $MgSO_4$, KCl, KCl plus NaCl, K_2SO_4 and H_3BO_3.

Data are presented in the present paper on the relationships between mineral nutrition and (1) storage root and vine weight; (2) general appearance of the leaf blades, storage roots, and fibrous roots; (3) mineral composition of the leaf blades, petioles, stems, storage roots and vines; and (4) carbohydrate composition of the leaf blades.

Methods

Two-gallon, glazed crocks were filled with Ottawa silica sand. The opening for drainage near the base of the crocks was filled loosely with glass wool to prevent escape of the sand. The crocks were placed out-of-doors on two benches raised about 3 feet above the ground, in 32 groups of 12 each. The benches were located in the open away from the shading effects of trees and buildings. Glazed, 50-liter crocks were placed in front of each group of 12 two-gallon crocks, and used as reservoirs for holding nutrient solutions. The 50-liter crocks containing nutrient solutions were covered to exclude sunlight and rain.

Uniform Triumph sweetpotato sprouts were planted one to a crock on May 9, 1945. The nutrient solutions were added as frequently as seemed necessary to supply moisture and nutrients. The daily addition of nutrient solution per crock varied from 400 cc. in May to 2700 cc. in September. The quantity of solution added was sufficient to obtain considerable drainage. The sand was flushed with water (tap water for some treatments and distilled water for others) once every two weeks in May and once every week in September in order to remove any salts that might have accumulated in the sand due to differential absorption.

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The following series of treatments were studied: (1) $NaNO_3$ series, in which the nitrogen was held at 10, 50, 100, 200, 400, 800 and 1600 p.p.m. of N; (2) NaH_2PO_4 series, in which the phosphorus was held at 2, 8, 25, 100, and 500 p.p.m. of P; (3) $CaCl_2$ series, calcium being held at 10, 100, 250 and 1000 p.p.m. of Ca; (4) $MgSO_4$ series, magnesium being held at 10, 100, 250 and 1000 p.p.m. of Mg; (5) KCl series, potassium being held at 6, 25, 100, 400 and 1600 p.p.m. of K; (6) KCl plus NaCl series, in which the potassium was held at 6, 25, 100, 400 and 1600 p.p.m. of K and all treatments received 50 p.p.m. of Na; (7) K_2SO_4 series, in which the potassium was held at 6, 25, 100, 400 and 1600 p.p.m. of K; and (8) H_3BO_3 series, in which boron was held at 1, 5 and 15 p.p.m. of B.

The salts were held at a constant concentration in each series, except for the single salt being varied, and the nutrient solutions received a uniform concentration of minor elements (except for the boron series). Boric acid was added at the rate of 1 p.p.m. of B; manganous sulphate at 0.5 p.p.m. of Mn; cupric sulphate at 0.1 p.p.m. of Cu; and stannic sulphate at 0.2 p.p.m. of Zn. Iron was supplied as needed, using ferric tartrate. The initial pH of the nutrient solutions (except for the K series) was adjusted to 5.0 with N/4 HCl and the leachate had a pH that varied between 5.5 and 7.0, except the 2-p.p.m.-P and 10-p.p.m.-N treatments, which varied between 4.0 and 5.0.

All of the above series, except the potassium series, received tap water. The tap water used had the following composition in p.p.m.: SiO_2, 14.9; Fe, 0.3; Ca, 8.2; Mg., 1.6; Na, 38.6; CO_3, 3.6; HCO_3 106.1; SO_4, 1.6; and Cl, 18.0.

The plants were harvested on September 21, 1945. The boron series was planted on May 8, 1946, and harvested on September 30, 1946.

Speed was considered essential in the harvesting manipulations, especially within each nutrient series. The first 5 fully enlarged leaves were collected from the tips of many individual stems. These were separated into blades and petioles, weighed, and placed into drying ovens held at 80° C. The entire vines were next harvested by cutting the stems at the surface of the sand and the detached vines weighed. All of the leaves remaining on the stems were stripped and the vines re-weighed. A sample of the stems was weighed and placed in an oven to dry. After all of the stems had been sampled, the storage roots were removed from the sand, counted, and weighed after the free water had evaporated from the surfaces. The roots were then cut longitudinally and one-fourth of each storage root saved for mineral analysis. The chemical composition of the whole vine is a calculated figure, and is based on the relative contribution of the blades, petioles, and stems on each constituent.

A.O.A.C. methods were followed in conducting the mineral determinations (**1**). Carbohydrates were determined following a modification of the Munsen-Walker-Bertrand method described in Loomis and Shull (**8**).

Another experiment started on July 21, and harvested on October 24, 1945, is referred to briefly. The procedure and other details were similar to those described above.

Results

Nitrogen series

The composition of the nutrient solutions (macronutrients) in the $NaNO_3$ series is shown in table I. It will be noted that all of the salts were held at a constant concentration, except $NaNO_3$, which was varied.

The data on the fresh weights of the vines and storage roots, as well as the mineral composition of the blades, petioles, stems, storage roots, and whole vines are shown in figure 1. The average weight of storage roots produced per plant was greatest with 50 p.p.m. N, while the weight of the vines was greatest with 200 p.p.m. N.

TABLE I

Composition of the nutrient solutions used in the $NaNO_3$ series. Data are in grams per liter

	Treatment—p.p.m. of nitrogen					
	10	50	100	200	400	800
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
$NaNO_3$	0.06	0.30	0.61	1.21	2.43	4.86
$MgSO_4 \cdot 7H_2O$–(100 p.p.m. Mg)	1.01	1.01	1.01	1.01	1.01	1.01
KCl–(100 p.p.m. K)	0.19	0.19	0.19	0.19	0.19	0.19
$NaH_2PO_4 \cdot H_2O$–(100 p.p.m. P)	0.44	0.44	0.44	0.44	0.44	0.44
$CaCl_2 \cdot 2H_2O$–(100 p.p.m. Ca)	0.37	0.37	0.37	0.37	0.37	0.37

The vines growing at different nitrogen levels differed in appearance and in leaf shedding. Leaves produced at 10 p.p.m. N were light green and there were very few leaves shed. Leaves produced on vines receiving 200 p.p.m. N were dark green and there was some leaf-shedding. Leaves produced with 800 p.p.m. N, and especially with 1600 p.p.m. N, were chlorotic. The plants in the last treatment died before the end of the experiment.

Storage roots produced with 10 p.p.m. N had a tan skin, were somewhat irregular in shape, and intermediate in size. Storage roots produced at 50 and 100 p.p.m. N had white skin, were regular in shape, with some large roots. Roots produced at all higher levels of nitrogen had white skin but were mainly small.

Fibrous roots appeared strong and firm with nitrogen levels up to 100 p.p.m., but those produced at 400 to 800 p.p.m. were somewhat soft and discolored, with the 200-p.p.m. treatment intermediate.

The percentage of nitrogen increased in the vines as the concentration of nitrogen increased in the nutrient solutions. Phosphorus followed the same trend as nitrogen up to 200 p.p.m. N. Potassium increased from 10 to 50 p.p.m. N and then decreased sharply beyond this point. The calcium

curve followed the potassium curve, except that the decrease in calcium was less marked than the decrease in potassium. Magnesium increased to 200 p.p.m. N and then decreased in the leaf blades and petioles but not in the stems.

Nitrogen, phosphorus, and potassium followed somewhat similar trends in the storage roots as in the vines. Calcium and magnesium were not depressed by higher concentrations of $NaNO_3$, such as occurred in the vines.

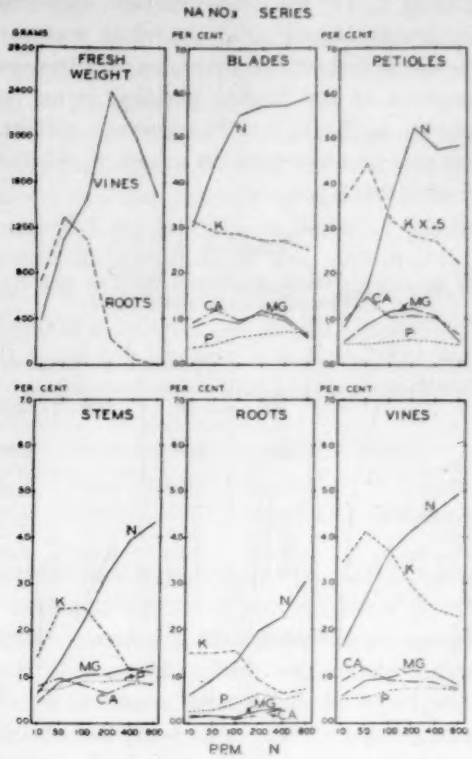

FIG. 1. The influence of variations in $NaNO_3$ on the chemical composition of the sweetpotato plant.

Carbohydrates (sugar and starch) in the leaf-blades had the following values on a dry weight basis: 10 p.p.m., 5.04%; 50 p.p.m., 3.18%; 100 p.p.m., 2.64%; 200 p.p.m., 1.83%; 400 p.p.m., 1.51%; and 800 p.p.m., 0.79%.

SODIUM DIHYDROGEN PHOSPHATE SERIES

The nutrient solutions were identical to those used in the $NaNO_3$ series, except that the nitrogen was held constant at 200 p.p.m. N and NaH_2PO_4 was varied. It will be noted that the 100-p.p.m. P treatment was identical with the 200-p.p.m. N treatment.

The data in the NaH_2PO_4 series on the fresh weights of the vines and storage roots, and the mineral composition of the blades, petioles, stems,

storage roots, and whole vines are shown in figure 2. The weight of storage roots produced per plant was greatest with 8 p.p.m. P, while the weight of the vines was greatest with 100 p.p.m. P.

Leaves produced with 2 p.p.m. P were dull green in color and there was some shedding of leaves. Dark green leaves were produced at 8 p.p.m. P and green leaves at 25 and 100 p.p.m. P; leaves produced at 500 p.p.m. P tended to be somewhat chlorotic.

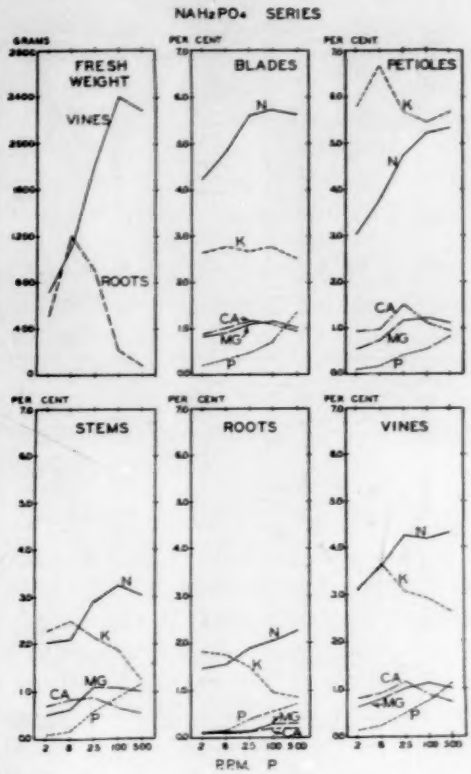

FIG. 2. The influence of variations in NaH_2PO_4 on the chemical composition of the sweetpotato plant.

Storage roots produced at 2 and 8 p.p.m. P were somewhat irregular and were tan colored in appearance. Roots produced at 25 p.p.m. P and higher were light colored with a regular form.

Fibrous roots produced at concentrations from 2 to 25 p.p.m. P were strong and firm, while those produced at 500 p.p.m. were somewhat discolored and soft. The 100 p.p.m. P treatment was intermediate between the above two extremes.

The percentage of phosphorus increased in the vines as the concentration of phosphorus increased in the nutrient solution. The percentage of nitrogen followed the same trend as the percentage of phosphorus to 25 p.p.m. P.

Except for an increase between 2 and 8 p.p.m. P, the percentage of potassium decreased as the concentration of phosphorus increased in the nutrient solutions. The percentage of calcium increased from 2 to 25 p.p.m. P and then decreased. The percentage of magnesium increased to 100 p.p.m. P and then decreased slightly. In many respects, the mineral composition of the vines in the NaH_2PO_4 and $NaNO_3$ series was similar.

Carbohydrates (sugar and starch) in leaf-blades had the following values

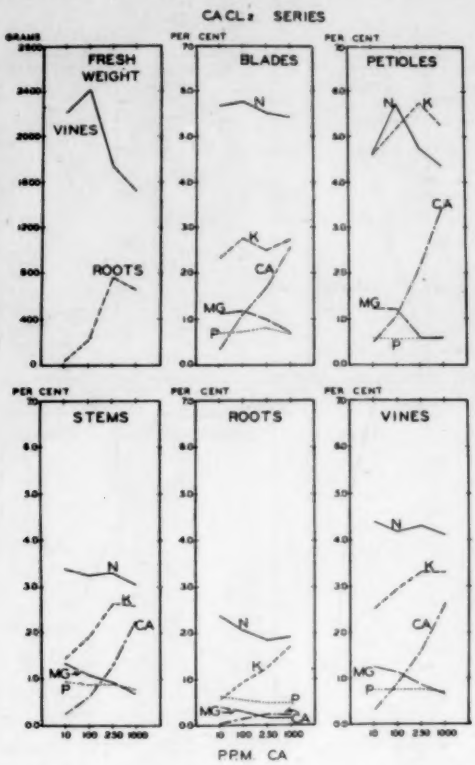

FIG. 3. The influence of variations in $CaCl_2$ on the chemical composition of the sweetpotato plant.

on a dry weight basis: 2 p.p.m., 4.13%; 8 p.p.m., 2.85%; 25 p.p.m., 2.36%; 100 p.p.m., 1.83%; and 500 p.p.m., 1.14%.

CALCIUM CHLORIDE SERIES

The nutrient solutions were identical to those used in the $NaNO_3$ series, except that nitrogen was held constant at 200 p.p.m. N and $CaCl_2$ was varied. It will be noted that the 100-p.p.m. Ca treatment was identical with the 200-p.p.m. N treatment.

The data on the fresh weights of the vines and storage roots, and the mineral composition of the blades, petioles, stems, storage roots, and vines

are shown in figure 3. Storage roots increased considerably from 10 to 250 p.p.m. Ca. Vine growth was not influenced as much as the storage roots by variations in calcium.

Leaves produced with 10 p.p.m. Ca showed some chlorosis, while leaves having a medium green color were produced with 100 and 250 p.p.m. Ca. The leaves produced with 1000 p.p.m. Ca were light green in color.

Storage roots produced with 10 p.p.m. Ca were soft, very small and crooked. Storage roots produced with all higher concentrations of calcium were white in appearance and had a smooth, regular form. Some large roots were produced with the higher concentrations of calcium.

Fibrous roots were soft and discolored with 10 p.p.m. Ca. Roots produced with 250- and 1000-p.p.m. Ca were firm, abundant and strong. The 100-p.p.m. Ca treatment was intermediate between the above extremes.

The percentage of calcium increased in the vines as the calcium content of the nutrient solutions increased. Simultaneous with the increase in the percentage of calicum was a marked decrease in the percentage of magnesium while nitrogen was depressed to a smaller extent.

Calcium and potassium increased and nitrogen, phosphorus, and magnesium decreased in the storage roots as the concentration of calcium increased in the nutrient solution.

Carbohydrates (sugars and starch) in leaf-blades had the following values on a dry weight basis: 10 p.p.m., 1.81%; 100 p.p.m., 1.83%; 250 p.p.m., 1.44%; and 1000 p.p.m., 0.85%.

Magnesium sulphate series

The nutrient solutions were identical to those used in the $NaNO_3$ series, except that nitrogen was held constant at 200 p.p.m. and $MgSO_4$ was varied; also, the 10-p.p.m. Mg treatment received enough Na_2SO_4 to bring the sulphate content of this treatment up to 131 p.p.m. S. It will be noted that the 100-p.p.m. Mg treatment was the same as the 200-p.p.m. N treatment.

The data on the fresh weights of the vines and storage roots, and the mineral composition of the blades, petioles, stems, storage roots and vines are shown in figure 4.

Leaves produced at 10 p.p.m. Mg tended to show some chlorosis. Green leaves were produced at 100 and 250 p.p.m. Mg, while the leaves produced at 1000 p.p.m. were again somewhat chlorotic.

Storage roots produced with 10 p.p.m. Mg were small and irregular; those produced with higher levels of magnesium were larger and white in appearance.

The fibrous roots produced at 10 p.p.m. Mg were soft, discolored and unhealthy in appearance. The fibrous roots produced with all higher concentrations, especially with 250 and 1000 p.p.m. Mg were discolored. Undoubtedly, insufficient calcium was present to make firm roots.

The percentage of magnesium increased in the vines and its parts as the concentration of magnesium in the nutrient solution was raised. Simul-

taneously with the increase in the percentage of magnesium, was a marked decrease in calcium and a moderate decrease in phosphorus and nitrogen, while the changes in potassium were erratic.

Nutrient changes in the storage roots were similar to those in the vines except for potassium, which increased as the concentration of magnesium increased in the nutrient solution.

Carbohydrates (sugars and starch) in leaf-blades had the following values: 10 p.p.m., 0.68%; 100 p.p.m., 1.83%; 250 p.p.m., 2.19%; and 1000 p.p.m., 1.45%.

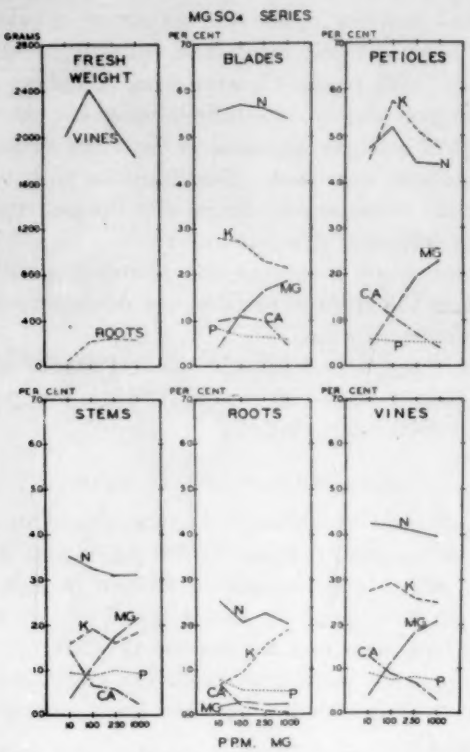

FIG. 4. The influence of variations in $MgSO_4$ on the chemical composition of the sweetpotato plant.

POTASSIUM CHLORIDE SERIES

The composition of the nutrient solutions used in the KCl series is shown in table II. It will be noted that all of the salts were held at a constant concentration, except for KCl which was varied.

Calcium was present in a concentration of 350 p.p.m. Distilled water was used in this series in order to exclude sodium from the nutrient solutions.

The data on the fresh weights of the vines and storage roots, and the mineral composition of the vines and storage roots are shown in figure 5. Storage roots increased as the K was increased from 6 to 100 p.p.m. K and

TABLE II

THE COMPOSITION OF THE NUTRIENT SOLUTIONS USED IN THE KCl SERIES. THE WEIGHTS OF THE SALTS ARE GIVEN IN GRAMS PER LITER

NUTRIENT SOLUTION	TREATMENT—P.P.M. OF POTASSIUM				
	6	25	100	400	1600
	gm.	*gm.*	*gm.*	*gm.*	*gm.*
KCl	0.01	0.05	0.19	0.76	3.05
$Ca(NO_3)_2 \cdot 4H_2O$ (200 p.p.m. N)	1.69	1.69	1.69	1.69	1.69
$Ca(H_2PO_4)_2 \cdot H_2O$ (100 p.p.m. P)	0.40	0.40	0.40	0.40	0.40
$MgSO_4 \cdot 7H_2O$ (100 p.p.m. Mg)	1.01	1.01	1.01	1.01	1.01

then decreased. Vine weight increased from 6 to 400 p.p.m. K and then decreased.

Leaves produced with 6 and 25 p.p.m. K showed marked deficiency symptoms. Leaves produced with 100 p.p.m. K were not as green as those produced at 400 p.p.m. K. Leaves produced with 1600 p.p.m. K tended to be slightly chlorotic.

Storage roots were small and firm with 6 p.p.m. K; large roots were produced with 100 p.p.m. K. As the concentration rose beyond 100 p.p.m. K the size of the storage roots became smaller.

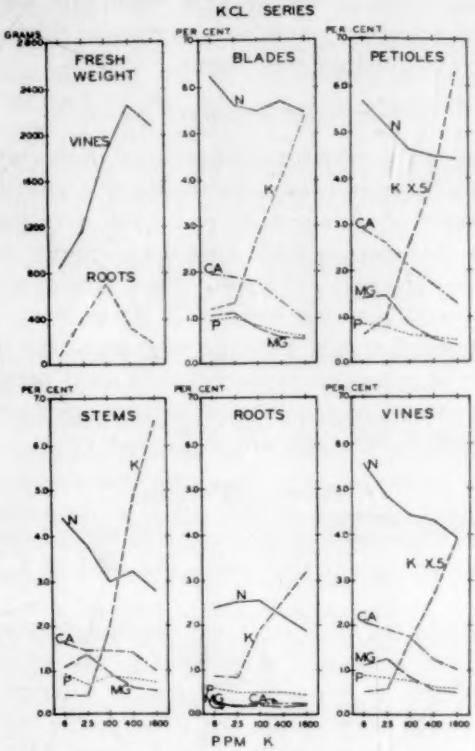

FIG. 5. The influence of variations in KCl on the chemical composition of the sweetpotato plant.

Fibrous roots were firm, tough and healthy with 6, 25 and 100 p.p.m. K. Fibrous roots produced with 1600 p.p.m. K were less firm and not quite as healthy in appearance as those produced at lower concentrations of potassium.

Potassium showed a very marked tendency to accumulate in the vine parts as more potassium was made available in the nutrient solutions. As the potassium increased in the vine parts, nitrogen, phosphorus, calcium and magnesium decreased.

Nutrient changes in the storage roots were not as marked as in the vines. As the concentration of potassium increased in the nutrient solutions, the percentage of potassium increased, nitrogen and phosphorus decreased, and magnesium and calcium showed little change.

Carbohydrates (sugars and starch) in leaf-blades had the following values: 6 p.p.m., 2.13%; 25 p.p.m., 2.35%; 100 p.p.m., 1.42%; 400 p.p.m., 1.08%; and 1600 p.p.m., 0.58%.

Potassium chloride plus sodium chloride series

This series was identical with the KCl series already described, except that all of the nutrient solutions contained 50 p.p.m. of sodium, supplied as NaCl.

The growth and chemical results were essentially the same as in the KCl series. Slightly greener leaves were present in this series, than in the previous series in which sodium was absent.

Potassium sulphate series

The composition of the nutrient solutions used in this series was the same as that used in the KCl series, except that K_2SO_4 was substituted for KCl.

The growth curves of storage roots and vines were the same as in the KCl series, except that storage roots were only slightly depressed by concentrations of potassium above 100 p.p.m. Some flowers were present, when harvested, on the plants that had received 25 p.p.m. K.

The over-all chemical trends were the same as in the KCl series except that the percentage of potassium in the different plant parts was, in general, less; also, the percentages of calcium and magnesium were depressed more and nitrogen less with K_2SO_4 than with KCl.

Boric acid series

The nutrient solutions used in the boric acid series were the same as the 200 p.p.m. N treatment except that boron was held at 1, 5, and 15 p.p.m. boron.

Storage root weight fell off sharply as the concentration of boron in the nutrient solution was increased. The fresh weight of storage roots per plant averaged 503 gm. at 1 p.p.m., 302 gm. at 5 p.p.m., and 55 gm. at 15 p.p.m. Vine weight (fresh) also fell off as boron was increased as is shown by the following figures: 2290 gm. at 1 p.p.m., 1851 gm. at 5 p.p.m.,

and 1087 gm. at 15 p.p.m. Leaves were severely injured by the higher concentrations of boron used.

The influence of increasing the boron concentration in the nutrient solutions on chemical composition was to increase slightly the percentages of nitrogen, phosphorus, potassium, calcium, and magnesium in the leaf blades, petioles and stems. The increase in the percentage of nutrients in the vines with increased boron in the nutrient solutions, was probably due to the influence of boron decreasing the vine growth.

Results from experiment harvested on October 24, 1945

The general trends on the growth of the vines and storage roots and the trends in mineral composition were the same as in the September harvest. Marked differences existed in the carbohydrate content of the leaf blades, at this time, from those sampled on September 21. The carbohydrate content of the blades was much higher than in the September harvest. No relationship now existed between the carbohydrate content of the blades and the weight of storage roots per plant in either the nitrogen or phosphorus series.

Discussion

Variations in the concentration of individual salts in the nutrient solutions brought about marked differences in the chemical composition of the sweetpotato plant. It is apparent that mineral deficiencies can be brought about by the mass effect of one ion suppressing the absorption of another. Hoagland (**6**) referred to the effect of one ion suppressing the absorption of another as "ionic competition."

Sodium was varied in both the $NaNO_3$ and NaH_2PO_4 series. With increasing concentrations of $NaNO_3$ or NaH_2PO_4 the percentage of potassium in the vines decreased first, calcium next, and magnesium last. Ratner (**10**) reported that plants may suffer from calcium deficiency in high sodium soils. Gauch and Wadleigh (**5**) found that sodium sulphate depressed calcium in bean leaves.

The percentages of nitrogen and phosphorus followed somewhat similar trends in both series. Some interrelations between the absorption of nitrogen and phosphorus have been reviewed by Beeson (**2**). Apparently different results have been obtained under different experimental conditions.

In the $CaCl_2$ series, both calcium and chloride ions were varied. With an increasing concentration of $CaCl_2$ in the nutrient solution, the percentage of calcium in the vines increased considerably, while the percentage of magnesium was markedly depressed. Calcium exerted a greater competitive effect against magnesium than against potassium. Hoagland (**6**) discussed the interrelations between calcium and potassium absorption. Apparently the depressing effect of calcium on the absorption of potassium is less marked than the influence of potassium on calcium absorption. An increase in the concentration of calcium chloride in the nutrient solution resulted in a general depression in the percentage of nitrogen in the vines but very

little effect on the phosphorus. The competing effect of the chloride ion against nitrate ions appears to be more pronounced than against phosphate ions.

In the $MgSO_4$ series, both magnesium and sulphate ions were varied. With an increasing concentration of magnesium sulphate in the nutrient solution, the percentage of magnesium in the vines increased markedly, while the percentage of calcium was sharply depressed and the percentage of potassium mildly depressed. Evidently, the competitive effect of magnesium ions was greater against calcium than against potassium. The mass influence of sulphate ions on the dissociation of calcium salts is probably an additional factor influencing calcium absorption. WALSH and O'DONOHOE (**13**) reported that the addition of magnesium sulphate to soil in field experiments depressed sodium absorption and accentuated potassium deficiency in Irish potatoes.

The percentage of nitrogen was consistently depressed in all experiments by increasing the concentrations of $MgSO_4$, while the percentage of phosphorus was not definitely affected. The sulphate ion, as the chloride ion, seems to depress the absorption of nitrate ions to a greater extent than phosphate ions.

In the KCl series, both potassium and chloride ions were varied. With an increasing concentration of KCl the percentage of potassium in the vines and its parts increased markedly, while the percentages of calcium and magnesium were markedly depressed. HOAGLAND (**6**) discussed the effect of potassium on decreasing the absorption of calcium and magnesium. LOEHWING (**7**) found that the addition of potassium chloride to a number of soils depressed the percentages of calcium and magnesium in dent corn, wheat, and oats. SIDERIS and YOUNG (**12**), WALSH and O'DONOHOE (**13**), PHILLIS and MASON (**9**), and others, have presented data on the depressing effect of potassium on the percentages of calcium and magnesium in plants. The percentages of nitrogen and phosphorus were markedly depressed by increasing the concentrations of KCl in the nutrient solutions. Evidently, the chloride ions were effective in depressing the absorption of nitrate and phosphate ions in the KCl series.

The influence of potassium sulphate on the chemical composition of the vines and storage roots was about the same as with KCl. In general, the percentages of nitrogen and phosphorus were depressed more with KCl than with K_2SO_4, while magnesium and calcium were depressed less. WALSH and O'DONOHOE (**13**) pointed out that the onset of magnesium deficiency was induced both by potassium and sulphate radicals.

The influence of increasing the boron concentration of the nutrient solution upon chemical composition of the vines and its parts, indicated no specific effects outside of increasing slightly the percentages of the various nutrients. The increased nutrient composition of the vines was probably a result of decreased vine growth, allowing a greater concentration of ions to accumulate.

EATON (3) reported that 15 p.p.m. of boron in nutrient solutions resulted in round, chunky sweetpotatoes, although the vines showed injury, while 1 p.p.m. resulted in stringy potatoes with healthy vines. These results are different from those obtained by the authors in the present experiments. Boron requirement likely varies with calcium supply and other factors.

The general health of the fibrous roots appeared to be influenced by the relative abundance of various cations. In the $NaNO_3$ and NaH_2PO_4 series, discolored and unhealthy roots were associated with high levels of sodium. In the $MgSO_4$ series, very unhealthy roots were associated with very low levels of magnesium and those at high magnesium levels were discolored. The detrimental influence of magnesium in displacing calcium from cell walls and cell contents is established. Nutrient solutions very low in $CaCl_2$ contained very unhealthy fibrous roots, while nutrient solutions high in calcium were in excellent condition. Fibrous roots developing in sand containing low concentrations of KCl were healthy, while those developing under very high concentrations of KCl were slightly discolored. All conditions which depressed calcium uptake by plants, resulted in unhealthy roots. According to SEIFRIZ (11) "the occurrence and severity of injury are determined by the ratio of magnesium to calcium." It is clear that nutrient ratio not only affects total absorption of different kinds of ions, but also affects the chemical composition and health of roots through which the ions are absorbed.

A relationship existed between carbohydrate level and storage root growth in some of the series but not in others in the September 21 harvest. In the $NaNO_3$ and NaH_2PO_4 series, a high carbohydrate level in leaf-blades was associated with optimum storage root growth. In the October 24 harvest, a relationship no longer existed between carbohydrate level and the abundance of storage roots in either of the two series mentioned. Cool weather in October may have been a contributing factor. Nevertheless, no general correlation between carbohydrate level in the leaf blades and storage root production existed when all the data are considered. EATON and RIGLER (4) observed that their data on fruitfulness and on carbohydrate and nitrogen accumulation afforded little basis for attaching any special significance to carbohydrate nitrogen ratios in the cotton plant.

The foregoing data indicate that a pronounced relationship existed between nutrient solution composition and storage root production. Vine growth was reduced far more than was the growth of the storage roots by low levels of nitrogen and phosphorus. Levels of calcium and magnesium sufficient to support vigorous vine growth was insufficient to support growth of the storage roots. Nutrient deficiencies may be brought about by unbalanced nutrient conditions. Such conditions may favor vine growth and be detrimental to storage root growth. It is noteworthy that maximum storage root production did not coincide with maximum vine growth (except in the boron series).

Summary

1. Triumph sweetpotato plants were grown about 4½ months in sand culture supplied with varying concentrations of $NaNO_3$, NaH_2PO_4, $CaCl_2$, $MgSO_4$, KCl, KCl + NaCl, K_2SO_4, and H_3BO_3.

2. Nutrient conditions optimum for storage root production were not, with one exception, optimum for vine growth. Concentrations of boron above 1 p.p.m. were injurious to both vines and storage roots.

3. Similar ions appeared to compete with each other, especially as reflected in the composition of the plants. Sodium appeared to depress the percentages of potassium and calcium to a greater extent than magnesium. Calcium sharply depressed magnesium, while the influence on potassium was much less marked. Magnesium sharply depressed calcium, while potassium was slightly depressed. Potassium depressed both calcium and magnesium. The anions also appeared to exert some competitive effect. The depressing influence of chloride and sulphate ions were especially marked in the potassium series in depressing the percentages of nitrogen and phosphorus in all the plant parts. On the other hand, nitrate and phosphate ions appeared to be mutually beneficial in aiding the absorption of the other.

4. No consistent relationship existed between carbohydrate level in the leaf-blades and storage root production.

5. The results indicate that nutrient deficiencies may result from improper nutrient balance. Such deficiencies (for example, calcium and magnesium) may result in a marked suppression in the growth of the storage roots without appreciably affecting the growth of the vines.

The authors wish to express their appreciation to the International Minerals and Chemical Corporation for help given them in conducting this study.

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A SURVEY OF THE POSSIBILITIES AND METHODS OF BREEDING HIGH-NIACIN CORN (MAIZE)[1]

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The importance of the predominating high-corn diet with its low niacin content as a cause of pellagra and other deficiency diseases in certain areas is well known. With this in mind, a survey was undertaken of the possibility of breeding corn with a higher niacin concentration and of methods that might be followed in such an undertaking. This paper reports the results of that survey, which, purposely, was made extensive rather than intensive. The data consequently are heterogeneous, bearing on sampling errors, fertilizer and geographic influences, the niacin in varieties, inbreds and hybrids, the increase and decrease of niacin concentration by selection and some other miscellaneous facts. They have one element in common—a bearing on the possibilities or methods of modifying the niacin content of corn.

BURKHOLDER *et al.* (**2**) note that sweet corns had a higher average concentration of niacin than did field corns. BARTON-WRIGHT (**1**) reported 31.0 micrograms of niacin per gram for 4 sweet corns grown in England, in comparison with 15.6 micrograms for 7 flint corns of various origins. Both of these findings suggest that the *Su su* alleles affect niacin concentration as well as the starchy-sugary condition of the grain. That this is true is shown by MATHER and BARTON-WRIGHT (**6**) who report practically complete dominance for the *Su* allele as far as niacin was concerned. BURKHOLDER *et al.* (**2**), however, conclude that in some six hybrids between inbreds of white field corn, niacin content was about intermediate, and that the higher-niacin hybrids came from the higher-niacin parents. This result suggests that niacin concentration may be determined by many genes of small individual effects and with dominance lacking. Such a mode of inheritance would be similar to that for protein as reported by HAYES (**3**) and by WINTER (**10**). The latter included also a report on modifying the oil content of corn by selection. The low-oil strain was achieved largely by reducing the size of the germ; in one very low-oil ear 80% of the grains were germless. "Student" (**8**) estimated that not less than 20 to 40 genes were concerned in determining oil content in Winter's experiment, possibly 200 to 400, and that the number was not at all likely to be of the order of 5 to 10.

[1] Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture; the Agricultural Experiment Station of the University of Tennessee; and the Department of Botany of Columbia University. The study was supported in part by grants from the Williams-Waterman Fund for the Combat of Dietary Disease of the Research Corporation of New York.

Methods of sampling and assay

The values reported for the niacin concentration of individual samples are the means of the titrations of the acid produced by *Lactobacillus arabinosus* in three or in four dilutions of an acid extract of the ground corn meal, according to the methods of SNELL and WRIGHT (7) as modified by KREHL, STRONG and ELVEHJEM (5). Four assays were made in each case, but if one differed from the other three by 2 or 3 micrograms, the mean of three was used. If no three agreed closely, the assays were repeated.

The error variance in sampling and assay was estimated from repetitive experiments made for the purpose. The estimates obtained in five such experiments and the average estimated from the pooled values are shown in table I. The estimates for the between samples variances were made from the means of the assays for the individual samples. Accordingly, they are not directly comparable with the variances within samples. For example, the variance for between samples in the last experiment, based on analysis of the 36 assays, is 4.70, much larger than the 0.69 for variance within samples. The 1.28, based on means, of course approximates 4.70/3.6, or 1.30.

TABLE I

THE ESTIMATED VARIANCE BETWEEN AND WITHIN SAMPLES IN FIVE EXPERIMENTS

No. of samples	Mean no. of assays	Estimated variance			
		Between samples*		Within samples	
		D/F	Variance	D/F	Variance
6	3.5	5	1.22	15	1.50
6	3.5	5	1.03	15	1.59
11	3.3	10	2.18	25	1.78
10	3.0	9	2.11	20	1.79
10	3.6	9	1.28	26	0.69
43	3.3	38	1.67	101	1.43

* These values were computed directly from the means of the assays for the individual samples; therefore, they should be multiplied by the mean number of assays per sample to obtain a value approximately comparable to the variances within samples.

The variance for between samples of 1.67 from the pooled estimates with 38 degrees of freedom provides a satisfactory base for a general error term for our purposes. As it is computed from the means of three or four assays on each sample, it includes such of that element of assay variability as was not eliminated by averaging. It is also close enough to the variances in the individual experiments to lead to no serious difficulty. The variation within samples is of interest primarily as showing its unimportance relative to that between samples, as already noted. The error variance could be reduced but little by increasing the number of assays. It also may be significant that the two experiments for which the most assays were rejected were the same as those having the higher variances both between and within experiments. It is not unlikely that this reflects variation in the personal

element, first, in having more discrepant assays and, second, in having more variation within those remaining. With 1.67 as the variance for a single sample, the standard error is 1.29, the standard error for a difference between two samples is 1.83, and 3.66, or twice this, may be taken as the least significant difference at the 5% point. These values are so small in relation to differences of real interest in most of our experiments that they usually can be disregarded.

In order to determine what would constitute an adequate sample of shelled grain, the following experiment was made. One part of a lot of shelled corn was ground and thoroughly mixed. From the other part, ten 2-gram samples were ground individually, extracted and assayed. The variance between the values obtained for these ten samples of whole grain was then compared with that for eleven 1-gram subsamples from the mixed meal. The variance for the whole-corn samples was 2.11 compared to 2.18 for the subsamples of meal. Clearly then, the 2-gram samples of whole corn were adequately representative. A two gram sample contains five to ten kernels or even more of very small kernel corn.

Some of the experiments involved the determination of niacin for individual ears. Accordingly, each of five ears of the Huffman variety was sampled by taking 25 kernels from opposite sides at the butt, at the middle, and at the tip of the ear. Analysis of variance showed extremely significant variation among the ears, while the F value for position on the ear in relation to error was 2.63, with 19.25 needed for significance at the 5% point. The standard error of a difference based on this analysis is 0.62. The same statistic estimated by treating the opposite samples from each part of the ear as duplicates is 0.74. Evidently, then, 25 kernels (or probably fewer in view of the results outlined in the preceding paragraph) from any part of an ear constitutes an adequate sample. This was the approximate number used in all individual ear estimates.

Data on the distribution of niacin concentration in the germ and in the endosperm indicate some variation in the proportions, but with reasonable equality. There is nothing to suggest, for example, that selection for high niacin would be selection for large germs, as in oil content, (**10**) and *vice versa*.

Varietal survey of niacin content

In a survey of white field corn, some 200 samples were obtained from seed dealers in various states. The source of seed, however, is no evidence of origin or adaptation for grain production. Thus, Adams Early and Truckers' Favorite, obtained in the South, are "field corns" (not sweet corns) used extensively for early roasting ears, and are not representative of southern grain varieties. Again, Iowa Silvermine, seed from Louisiana, is still a Corn Belt variety. The average values in table II, therefore, are based on assays of only those varieties known to be adapted for grain production in the states indicated. This gives a better geographical picture of niacin distribution than would the complete data. It is evident that the southern

corns have a somewhat higher niacin concentration than those from the north. The difference is not of nutritional importance, but would make adapted varieties in the South a better foundation for niacin breeding than the less adapted varieties from the Corn Belt. The concentrations found in some individual more-or-less-standard southern varieties are reported in table III. Hickory King, while it is grown for grain on a small scale, is grown very widely for eating as a vegetable. Its low niacin content relative to the higher ones reported for some sweet corns (**2**) accordingly seems of interest.

TABLE II

THE NIACIN CONCENTRATION IN SAMPLES OF WHITE FIELD CORN FROM AND ADAPTED TO DIFFERENT STATES

STATE	NO. OF SAMPLES	NIACIN, MICROGRAMS PER GRAM	
		MEAN	RANGE
Louisiana	5	27.4	25.8–30.0
Georgia	4	26.8	22.0–31.5
Florida	5	26.6	24.7–30.9
South Carolina	4	25.8	23.3–30.4
Tennessee	3	24.8	22.0–26.2
Texas	6	23.6	20.5–28.1
Illinois	19*	18.6	14.8–25.4
Indiana	3*	18.3	14.8–21.6
North Dakota	6	18.6	15.2–21.0

* White hybrids.

TABLE III

THE NIACIN CONCENTRATION, MICROGRAMS PER GRAM, OF SOME OF THE MORE-OR-LESS STANDARD SOUTHERN VARIETIES OF WHITE FIELD CORN

VARIETY	NO. OF SAMPLES	NIACIN CONCENTRATION
Tuxpan	1	30.9
Whatley	4	30.1
Mosby	2	29.8
Hastings	4	26.9
Garrick	2	26.9
Sentell	1	26.3
Thompson	1	26.1
Ellis	2	24.8
Sureropper	4	23.8
Mexican June	3	23.5
Tenn. Red Cob	4	22.9
Douthit	1	22.2
Huffman	40*	22.0
Hickory King	3	20.8

* 40 individual ears.

Environmental influence

Any program of breeding for niacin content in corn must involve the assay of parent and progeny material on a considerable scale. Accordingly it is important to know the extent to which niacin content may be influenced by the environment. Aside from its interest as a possible element in the

sampling error, environmental influence on niacin content might provide a means of modification, *per se*, if this influence were of sufficient magnitude. Nothing in our data indicates that the latter is the case.

Production practices

Advantage was taken of some fertilizer and similar experiments to determine the influence of variation in practices followed on niacin concentration. One of these experiments involved the application of fertilizer at different rates and in different ways. The writers are indebted to Dr. J. B. Washko who conducted the experiment at the Tennessee Experiment Station, for the samples assayed. The data are shown in table IV. Analysis failed to show any significant (5% point) difference among the eight treatments. If the higher concentration in the sample receiving no fertilizer is real, it could be due to a situation illustrated more clearly in the next experiment. The writers are inclined to think that it is fortuitous, however, as the growth of all plots was reasonably normal.

TABLE IV

CONCENTRATION OF NIACIN IN MICROGRAMS PER GRAM IN HYBRID TENNESSEE 10 CORN UNDER DIFFERENT FERTILIZER TREATMENTS NEAR KNOXVILLE, TENNESSEE, IN 1944

Fertilizer applications (N–P–K)					
2–12–16 At planting	10–10–10 At plowsole			10–10–10 Broadcast	
	0 lbs.	500 lbs.	1,000 lbs.		
	Niacin	*Niacin*	*Niacin*	*Niacin*	
0 lbs.	32.5*	30.1†	25.9†	.....	0 lbs.
0 lbs.	.....	.....	.....	26.4*	500 lbs.
200 lbs.	26.3*	28.0†	26.0†	.....	0 lbs.
200 lbs.	.....	.....	.....	27.5*	1000 lbs.

* Mean for 2 plots. † Mean for 4 plots.

Another experiment conducted by Dr. Washko near Knoxville, involved different applications of potash to corn already showing symptoms of potash starvation. The yields and niacin concentration are shown in table V, the yields being reproduced from WASHKO (9). In spite of the striking differences in yield there was no significant difference in niacin concentration due to time of application or to differences in rate when some potash was applied. The difference between no potash and some potash, however, was highly significant. This difference appears to be only a reflection of the fact that the dry weight of seed was restricted more by the starvation conditions than was the total niacin in the seed.

The niacin content was determined for corn grown in two other experiments involving fertilizer applications. In one of these, nitrogen was applied differentially to plots on which different green manures had and had not been turned under. The differences in niacin concentration were small, appeared inconsistent, and were not significant at the 5% point.

TABLE V

ACRE YIELDS OF SHELLED CORN AND NIACIN CONCENTRATION OF SAME WHEN POTASH WAS APPLIED AT DIFFERENT TIMES AT DIFFERENT RATES

POTASH APPLIED PER ACRE		POTASH APPLIED ON		
		JUNE 14	JULY 3	JULY 17
None	Yield*	3.7	8.7	8.1
	Niacin†	30.3	28.6	Discarded
25 lbs.	Yield	15.9	21.4	11.1
	Niacin	21.5	18.5	22.8
50 lbs.	Yield	27.9	21.9	10.2
	Niacin	22.3	21.8	20.7
100 lbs.	Yield	30.8	26.4	14.9
	Niacin	20.6	23.1	19.2

* Acre yields of shelled grain, bushels. Data from Washko (9).
† Micrograms of niacin per gram.

The other experiment involved eight different fertilizer treatments on each of six different farms. The applications in pounds per acre were:

N	0	32	32	32
P_2O_5	0	0	0	40
K_2O	0	0	50	50

with the P_2O_5 applied as superphosphate, as triple superphosphate, and as fused rock phosphate through 6, 40, and 80-mesh sieves. The maximum spread between two treatments averaged for all farms was from 22.4 to 26.3. The F value for treatments was less than required for significance at 5%. The F value for differences due to farms, on the other hand, was 6.13, far exceeding the 3.60 needed at the 1% level. The maximum spread between the averages for two farms for all eight treatments was from 21.3 to 27.8, or 6.5 micrograms per gram, and the differences between the two farms were consistent for all treatments. No reason is known for this apparent influence of environment. It suggests no difficulty, however, in obtaining critical comparisons within fields such as are used in a breeding program.

GEOGRAPHIC INFLUENCE

The possibility of geographic and of genetic influence was surveyed through the assay of seed of different inbred lines grown in different states. The lines used had been selfed until they were uniform, and hand self-pollinated seed was supplied by the corn breeders in the states designated. The data for lines received from three or more stations are shown in table VI. The various averages permit comparisons of several lines when grown at different locations.

The variance was analyzed for three groups of the material: (1) The three Louisiana lines, grown at five locations (Group A); (2) The same lines and the three in Group C, grown at 4 locations; (3) The eight lines in Group H, grown at three locations. These are, of course, not independent

groups, but each differs somewhat from each of the other two. Using line × location interaction as an error term, there was no significant (5%) variation due to location, as might be expected from the small differences due to that cause as seen in table VI. Neither was there significant varia-

TABLE VI

NIACIN CONCENTRATION, MICROGRAMS PER GRAM, IN SELF-POLLINATED SEED OF INBRED LINES FROM DIFFERENT STATES. AVERAGES ARE FOR THE SAME LINES GROWN IN THE DIFFERENT STATES

DESIGNATION	NUMBER AVERAGED	NIACIN, MICROGRAMS PER GRAM, WHEN GROWN IN:						
		TENN.	N. C.	MISS.	KY.	GA.	LA.	MEAN
La. 2–2	.....	27.7	32.9	21.7	.....	28.2	27.9	27.7
La. 10	.....	36.8	29.9	41.1	.....	33.3	29.2	34.1
La. 44	.....	33.3	26.1	31.5	.....	28.6	20.0	27.9
La. 62	.....	30.4	35.9	.....	.....	29.8	30.5	31.7
Group A	3	32.6	29.6	31.4	.....	30.0	25.7	.....
Group B	4	32.1	31.2	.....	.....	30.0	26.9	.....
CI. 21	.....	31.9	29.2	30.9	27.7	34.3	.....	30.8
N. C. 7	.....	20.4	19.0	17.4	19.0	20.7	.....	19.3
KYS	.....	22.7	22.2	24.5	18.3	23.8	.....	22.3
Group C	3	25.0	23.5	24.3	21.7	26.3	.....	.....
CI.7	.....	21.2	.....	24.7	21.5	.....	.....	22.5
Ky. 35–7	.....	24.9	.....	22.1	22.5	.....	.....	23.2
N. C. 12	.....	27.9	23.4	29.1	.....	.....	.....	26.8
N. C. 13	.....	20.2	18.8	22.1	.....	.....	.....	20.4
Group D (C+2)	5	24.2	.....	23.9	21.8	.....	.....	.....
Group E (C+2)	5	24.6	22.5	24.8	.....	.....	.....	.....
Group F (C+4)	7	24.2	.....	24.4	.....	.....	.....	.....
Group G (A, C)	6	28.8	26.6	27.9	.....	28.2	.....	.....
Group H (A, E)	8	27.6	25.2	27.3	.....	.....	.....	.....
Group I (B, E)	9	27.9	26.4	.....	.....	.....	.....	.....
Group K (A, F)	10	26.7	.....	26.5	.....	.....	.....	.....

tion among the three Lousiana lines in the Group A analysis. The other two analyses, however, showed significant (1%) variation among the lines. Consideration of this variaton belongs in the next section.

Besides the nine lines from North Carolina and Tennessee reported on in table VI, seven others from both states also were assayed. The results for these follow:

LINE	T13	T14	T61	T83	T85	NC34	NC37	Av.
Tenn.	55.5	18.7	27.0	29.0	31.0	24.2	16.2	28.8
N. C.	51.0	17.2	25.7	22.6	28.1	19.4	15.7	25.7

The concentrations for the Tennessee-grown material were consistently higher. Accordingly, these values and those for the nine lines from table VI were analyzed for variance. The F value for Location/Interaction is 5.86, with 4.54 needed for significance at the 5% level. Again, then, there is a definite suggestion of variation due to locality. The average difference here of 3.1 micrograms, however, is of negligible importance. In summary, it

may be said that the niacin concentration appears to be affected exceedingly little by even marked differences in environment, which therefore would not be a complicating element in breeding for higher niacin content. On the other hand, it is strongly suggested that environment sometimes does have a consistent though minor effect, in what ways is not known.

Genetic variation

If nurture has little influence on the niacin concentration of corn, what about nature? The survey of open-pollinated varieties previously reported showed wide differences. Similar difference, then, would be expected within varieties. That these exist is shown by the data in table VII, which reports

TABLE VII

SUMMARY OF MEAN NIACIN CONCENTRATION, MICROGRAMS PER GRAM, FOR 24 LONG-TIME INBREDS ASSAYED. THE FIRST 14 LINES LISTED ARE WHITE AND THE LAST 10 ARE YELLOW

INBRED	NIACIN	INBRED	NIACIN	INBRED	NIACIN
T13	53.3	NC34	21.8	Ky. 35–7	23.2
La. 10	34.1	T18	20.8	CI.7	22.5
La. 62	31.7	T × 61M	18.3	KYS	22.3
T85	29.6	T14	18.0	T8	21.7
La. 44	27.9	NC37	16.0	NC13	20.4
La. 2–2	27.7	Ind. 33–16	13.9	T202	19.6
T61	26.4	CI.21	30.8	NC7	19.3
T83	25.8	NC12	26.8	K4	15.6

the mean niacin concentrations for the 24 long-time inbreds that have been assayed. The range for the white lines is from 13.9 to 53.3 for Ind. 33–16 and T13; that for the yellow lines is from 15.6 to 30.8 for K4 and CI.21. Again, the variation for six Tennessee lines, all out of the Neal Paymaster variety, is from 18.0 to 53.3 for T14 and T13, or a ratio of nearly 1 to 3.

NIACIN CONCENTRATION IN HYBRIDS

The niacin concentrations for a number of yellow inbred lines and for F1 seed of some of the hybrids between them are shown in table VIII. The influence of both parents is evident in the hybrids, which are largely intermediate. There is some evidence, however, that the seed parent had greater influence than the pollen parent. This difference is not shown where the differences were small, but for two pairs of reciprocals involving CI.21 (30.8) and T202 and CI.7 (Av. 21.1), the hybrids having CI.21 as seed parent had an average concentration of 32.5 compared to 20.4 for the average of the reciprocals. A similar comparison can be made between the reciprocals of T13 and T61, having 53.3 and 26.1 micrograms of niacin per gram, respectively. Hybrid T13 × T61 had a concentration of 40.3, whereas its reciprocal had only 30.4 micrograms per gram. This situation is what would be expected if niacin were determined by genes with dominance lacking, the two genomes contributed by the polar nuclei to the endosperm

having more influence than the one genome contributed by the sperm. It is an entirely different situation from that reported by MATHER and BARTON-WRIGHT (**6**). They found that *Su* (starchy) was completely dominant to *su* (sweet), as far as nicotinic acid was concerned. In the light of our data, this would seem to be a secondary, pleiotropic influence of the *Su su* alleles. Again, however, this may be the effect of the *Su* (starchy) seeds being heavier. (Differences in niacin in 1947 experiments with

TABLE VIII

THE NIACIN CONCENTRATION, MICROGRAMS PER GRAM, IN SOME YELLOW INBRED LINES OF CORN AND SEED OF THEIR F_1 HYBRIDS†

SEED PARENT AND NIACIN CONCENTRATION	POLLEN PARENT AND NIACIN CONCENTRATION								
	T202 19.6	CI.7 22.5	CI.21 30.8	T8 21.7	K4 15.6	Ky35–7 23.2	NC13 20.4	T204 ?	KYS 22.3
T202 19.6	——	23.3	21.5	21.4	20.7	23.2	.....	21.5	20.2
CI.7 22.5	23.7	——	19.2	21.2	.....	.....	.....	26.9	20.4
CI.21 30.8	30.9	34.0	——	.....	.....	.....	.....	43.6	.....
T8 21.7	20.5	23.5*	.....	——	21.2	22.2*	.....	.....	24.8
K4 15.6	16.0	19.1	23.9	16.9	——	.....	.....	.....	19.7
Ky35–7 23.2	21.2	20.8	.....	.....	.....	——	23.8*	23.9	.....
NC7 19.3	.....	.....	.....	.....	.....	19.2*	20.1	.....	.....
T204 ?	25.0	20.6	26.0	.....	.....	27.3	.....	——	.....
KYS 22.3	21.2	22.2	28.8*	21.4	22.2	.....	.....	.....	.....

* Hand-pollinated F2 seed.
† Assays for reciprocals, when available, are in lower left and upper right triangles.

sweet corn were too large to be explained by differences in seed weight.) KIESSELBACH (**4**) reported starchy seeds 20–25% heavier than comparable sweet seeds. Analysis of samples of waxy corn obtained from Dr. Merle T. Jenkins of the U. S. Department of Agriculture suggests that the *wx* gene also may tend to increase the niacin content slightly, though not as much, apparently, as does the *su* gene. Here, too, *Wx* (starchy) seeds are reported (**4**) heavier than comparable waxy seeds, though by a smaller quantity. These points need further research.

The niacin concentrations in the seed of 15 double-cross combinations and for 13 of their reciprocals are shown in table IX. The calculated concentrations for the parent single crosses, when possible, also are shown. These are simply the arithmetic means for the two parent inbred lines as reported in table VII.

The results for the white hybrids are dominated by the fact that T13 with its niacin content of 53.3 is involved in all seven crosses, coming in with T61 in five of them. Even so, there are some obvious differences between the crosses of T13 × T61 with the Louisiana lines and the crosses involving only the Tennessee (T) inbreds. The former, with T13 × T61 used as a seed parent, are essentially equal to the calculated value for that parent. In the latter, the parent singles including T13 exercise much less influence. The four T lines are from Neal Paymaster, whereas the Louisiana lines are not from that variety. It is not clear, however, how that fact could explain the results.

TABLE IX

NIACIN CONCENTRATION, MICROGRAMS PER GRAM, IN THE SEED OF CERTAIN DOUBLE CROSSES, AND THE CALCULATED CONCENTRATION FOR THE PARENTS

Parent A	Niacin concentration				Parent B
	A*	A × B	B × A	B*	
WHITE CROSSES:					
T13 × T61	39.9	39.1	30.6	31.0	La44 × La10
"	39.9	39.6	21.9	.....	La501 × La503
"	39.9	40.4	.....	32.9	La10 × La62
"	39.9	38.8	.....	27.8	La44 × La2–2
"	39.9	28.8	18.4	19.4	T14 × T18
T13 × T14	35.7	26.0	24.7	23.6	T18 × T61
T13 × T18	37.1	25.3	22.4	22.2	T14 × T61
YELLOW CROSSES:					
KYS × T8	22.0	23.4	25.3	21.1	T202 × CI.7
T202 × KYS	21.0	25.7	22.4	19.9	NC7 × NC13
T202 × CI.21	25.2	16.7	15.7	19.9	"
CI.7 × KYS	22.4	24.3	22.4	19.9	"
"	22.4	24.0	23.2	18.7	K4 × T8
T202 × KYS	21.0	26.3	23.1	22.9	CI.7 × Ky. 35–7
T202 × CI.21	25.2	38.4	25.9	22.9	"
CI.7 × T8	22.1	24.2	23.7	19.0	K4 × KYS

* The means for the two parent lines as shown in table VII.

With a single exception, the yellow double crosses all equal or exceed the calculated values for their higher single-cross parents. All of the differences are small except that of 38.4 micrograms per gram in (T202 × CI.21) (CI.7 × Ky.3 5–7). Their consistency, however, suggests that some definite influence may be involved. The discrepant behavior of both reciprocal crosses of T202 × CI.21 with NC7 × NC13 also suggests the possibility of some complicating situation.

As a whole, however, the results for the double crosses are consistent with those for the single crosses. Both suggest that the inheritance of niacin concentration is determined primarily by a considerable number of genes with dominance lacking. For our purposes, the results emphasize the possibilities of selection. They also show the necessity of using controlled pollination, either by hand or by isolation, when attempting to evaluate the niacin content of different inbreds or hybrids.

Selecting for niacin concentration

Once-selfed ears of the Franklin and Huffman varieties were assayed as a preliminary to selecting for niacin content. The Franklin is a yellow dent variety from Oklahoma. The Huffman is a large, late, single-eared white dent from Tennessee, and has excellent milling quality. The means and standard deviations for the samples of the two varieties are shown in table X. The last two columns in the table show the means plus two and plus three times the standard deviations. Individual ears departing from the mean to this degree would be expected about once in 20 and once in 100 times, respectively. On that basis, the chance of finding ears in this kind of material with concentrations much in excess of those in the last columns would be remote. The distributions are somewhat skew, however, tailing toward the high-niacin side. Because of its larger mean, its greater variation, and because it fitted into the program better, the Huffman variety was chosen for the selection experiments.

TABLE X

THE MEAN AND THE MEAN PLUS TWO AND PLUS THREE TIMES THE STANDARD DEVIATION* FOR NIACIN CONCENTRATION IN INDIVIDUAL EARS OF THE FRANKLIN AND THE HUFFMAN VARIETIES OF CORN

VARIETY	NO. OF EARS	NIACIN CONCENTRATION, MICROGRAMS PER GRAM			
		MEAN	S.D.	MEAN PLUS	
				2 (S.D.)	3 (S.D.)
Franklin	24	20.5	3.4	26.9	30.0
Huffman	43	22.0	4.9	31.6	36.3

* The standard deviations are shown as calculated from a single mean for each ear. The value of 1.67 (as error variance, based on the repetitive experiments) was deducted from the variance before multiplying by 4 and 9, and then re-added to provide the squares of 2 and 3 times the standard deviations used for the data in the last two columns.

Of the 43 once-selfed ears of Huffman assayed, eight were planted in ear rows in 1945, and 60 self pollinated ears were obtained and assayed. Of the eight parent S1 ears, four were chosen for high-niacin concentration and four for low-niacin concentration. From the 60 S2 ears, 24 with different niacin concentrations were selected and planted in ear rows in 1946. From these, 153 S3 ears were obtained representing the various S2 progenies. The niacin concentration in the S1 and S2 ears planted, and the concentrations in the S2 and S3 progeny by classes and means are shown in table XI. The S1 families with the higher seed-ear concentrations are at the top of the table. The same placement is followed for the S2 branches within the families. Thus, seed ear H29 had a niacin concentration of 37.8 micrograms per gram; its nine progeny ears averaged 32.5 micrograms, the highest being H29–7 with 44.6 micrograms. The five S3 progeny ears of H29–7 had the highest mean of any progeny in that generation, and contained one ear with a concentration of 50.6 micrograms per gram.

The tendency between and within families for niacin concentration to follow that of the parents is very strong. With 3.66 as the least significant difference at the 5% level (based on the repetitive experiments), many of the apparent exceptions are obviously well within the limits of sampling.

TABLE XI

THE NIACIN CONCENTRATION, MICROGRAMS PER GRAM, FOR S1 AND S2 SEED EARS OF HUFFMAN CORN, AND THE CONCENTRATION FOR THEIR S2 AND S3 PROGENIES BY CLASSES AND MEANS

PEDIGREE		NIACIN IN		DISTRIBUTION OF S2 AND S3 PROGENY EARS FOR NIACIN CONCENTRATION							
		SEED	PROGENY	10.–14.9	15.–19.9	20.–24.9	25.–29.9	30.–34.9	35.–39.9	40.–44.9	45.–
S1	S2	EARS	MEAN								
H29–		37.8	32.5				5	2		2	
	–7	44.6	42.6						1	3	1
	–3	40.4	30.2			1	1		1		
	–2	33.8	25.7		2	1		3			
	–8	27.5	30.8			2		4		1	
H14–		35.5	33.1		1			3	2		
	–6	39.7	30.1		1		3	2	1	1	
	–2	38.2	42.7						1	1	
	–3	34.5	34.0					4	1		
	–1	19.4	24.8		1	1	5				
H38–		29.7	26.9		1	1	5	2			
	–2	33.4	29.8				3	2			
	–1	32.0	36.5					3	2	1	
	–4	25.6	27.8			1	2	2			
	–9	17.6	20.4		2	2					
H25–		26.9	22.8		1	5	1				
	–7	26.3	28.4				5	2			
	–2	20.0	19.9		5	6					
	–3	19.8	23.9			5	3				
H8–		16.9	24.3		1	3	2	1			
	–3	30.9	23.2		2	5	3				
	–7	17.8	16.4	1	4						
H6–		14.9	21.4		5	2	2				
	–4	26.6	22.9			7	1				
	–3	26.2	19.7		6	3					
	–6	19.7	21.9		2	7					
	–5	18.4	18.5	1	6	2					
H18–		14.3	20.8		3	2	1				
	–1	25.2	20.8		2	3					
H5–		13.9	21.1		4	2	1				
	–2	28.0	20.8		2	2					
	–1	15.8	14.3	3	2						

There are two definite tendencies of departure. The S2 progeny of each of the four "high" families regress downward toward the varietal mean (22.0); those of the four "low" families regress upward toward that mean. Only in family H25 was there no S2 ear with a higher concentration than its

S1 parent. These regression tendencies are almost lacking for the S3 progeny means. In fact, the differences tend to be rather to the S1 parent ears than to the variety. As a measure of progress, it may be noted that the 15 S3 ears (from families H29, H14 and H38) planted in 1947 for continuing high niacin selection had a mean concentration of 41.4 micrograms of niacin per gram. This is higher than any but one (H29–7) of the individual seed ears planted in 1946. There is no doubt, then, that the niacin concentration of corn has been raised quickly by selection in selfed lines.

The niacin concentration was determined for 40 open-pollinated ears of Huffman. The mean concentration was 21.4 micrograms per gram, with a range of 12.1, and a variance of 9.379. These values compare wth corresponding ones of 22.0, 23.9, and 24.139 for the 43 selfed ears. The latter, of course, were influenced only by their own kinds of pollen, whereas the open-pollinated ears received random samples of pollen from the variety. If the influence of pollen were additive and equal to that of the egg and polar nuclei combined, the variance for the selfs would be four times that of the open-pollinated ears. Or, with an additive effect for the pollen of one-half, the ratio for the variances would be 2.5 to 1. Multiplying 9,379 by 2.5 gives 23.448 to compare with 24.139 for the selfed ears. This is in good agreement with the evidence from some of the other experiments that the pollen parent influences the niacin content but has less influence than the seed parent. It should be kept in mind, however, that in some experiments this tendency was not evident. Aside from its theoretical interest, this result further emphasizes the need of controlled pollination in niacin studies.

Crossing for re-selection

The data as accumulated indicated that the inheritance of niacin content is governed primarily by many genes of small individual effects. If so, selection in selfed lines would rapidly reach a limit of effectiveness. At that stage, different lines would be high because of the larger proportions of plus-niacin genes they carried. They would differ, however, as to the particular genes they carried. Accordingly, crossing among high-niacin strains should restore heterozygosity and variability, and provide opportunity for further selecting. To check on these possibilities, crosses among some of the higher-niacin strains of Huffman were obtained in 1946. The niacin concentration of the parent (S2) ears planted and of the individual crossed ears obtained are shown in table XII. The means and distributions of selfed ears obtained from the same parent ears were shown in table XI. The crossed ears indicated by daggers were planted in 1947 for selfing and further possible selection. It was planned to cross T13 (with its concentration of 53.3) with some of the high Huffmans, but this was not possible in 1946. Until the niacin concentration of the F2 and F3 seed ears is available the possibilities of this attack are unknown. The background is given here only as a report of progress.

Discussion

Nothing has been noted during the course of these experiments to show a necessary relation between high niacin concentration and any favorable or unfavorable agronomic characters. There accordingly is little doubt that satisfactory lines of corn could be established having a niacin concentration of at least 50 micrograms per gram. These lines could be used to produce high-niacin hybrids. It cannot be emphasized too strongly, however, that a high-niacin hybrid will be worthless commercially unless it is otherwise

TABLE XII

NIACIN CONCENTRATION, MICROGRAMS PER GRAM, OF S2 EARS OF HUFFMAN CORN AND OF INDIVIDUAL F1 HYBRID SEED EARS

S2 PARENTS		NIACIN CONCENTRATION OF INDIVIDUAL CROSSED EARS*					
PEDIGREE	NIACIN						
H14–2	(38.2)	33.8	52.0†				
H29–3	(40.4)	30.7	36.8†				
H14–6	(39.7)	40.8†	50.0†				
H29–7	(44.6)	36.9	37.6†	33.3			
H14–3	(34.5)	31.6	35.8	27.4			
H38–1	(32.0)	39.1†	29.8	31.9			
H29–2	(33.8)	24.2†	24.8	26.3	26.2		
H38–2	(33.4)	27.0	26.9	26.4	32.7	29.8	31.6
H38–2	(33.4)	34.2†	27.0				
H 8–3	(30.9)	26.0	34.3	28.0			

* The crosses were made between the stocks as shown by the pairing. There is no necessary relation between the individual ears; i.e., the ear of H14–2 × H29–3 with 33.8 may or may not have been pollinated from the plants producing 30.7 or 36.8 micrograms. Many of the ears were crossed with mixed pollen from several plants.

† Ears planted for selfing in 1947.

satisfactory. That is, it must yield well, remain erect in the field, have adequate husk protection from insects, and be resistant to the more important corn diseases. Finally, it must comply with the personal preferences of those who grow it. Thus, some farmers will want yellow corn, others white, some will want a single-eared, others a prolific variety, and so on. Moreover, these personal predilections frequently have more weight in the farmers' choice of a hybrid than do some of the characteristics which have real importance. BURKHOLDER *et al.* (**2**) have suggested that a special corn should be bred for use by those whose dietary is conducive to pellagra and other deficiency diseases. It may be stated categorically that getting such people to grow a special high-niacin corn would be far more difficult than to get the millers to fortify their products with added niacin. The problem could be solved from the corn end only by having nothing but high-niacin corn grown in the deficiency areas.

The problem of breeding corn for high niacin, then, can not be undertaken as an isolated project but must be integrated with the whole breeding program. Something of what this would mean with a variety like Huffman

is suggested by our data. Only one, or possibly two, foundation ears out of 43 were high enough in niacin to be good prospects. If a general breeding program were to be started with 50 S1 ears, therefore, it would be necessary to self 1,000 or 2,000 from which to get the 50 needed. In later generations these would have niacin distributions similar to those for the H29 and H14 families in table XI. The considerable number that would have to be rejected for this one characteristic is evident. But this is only one of several important characteristics which must be combined in a single strain. Moreover, high niacin appears to be easier of achievement than some of the other, more complex characters which can not be evaluated so objectively and certainly. How the difficulties increase geometrically is obvious; and these would have to be overcome, not with one hybrid but with several, in order to meet the needs of different growing seasons and to avoid the prejudices of different farmers.

Another possibility, the only one for such material, would be to increase the niacin concentration of existing inbreds by crossing and selecting. This, too, presents difficulties. It should be simple either to increase the niacin concentration or to "recover" the more important elements of the original inbred, but far from simple to do both. The results from our hybrids should supply specific information on this question. The conclusion seems plain, then, that satisfactory high-niacin corn can be developed, but that its development would require a very considerable effort. Whether such effort is justified is a question beyond our province to discuss.

Summary

1. Sampling studies for niacin concentration showed 2-gram samples of shelled corn and 25-kernel samples from any part of an individual ear to be adequately representative.

2. Varieties of white dent corn differ widely in their niacin concentrations, the southern varieties tending to be higher than northern varieties.

3. Extreme differences in production practices, such as fertilizer applications, green manures, etc., resulted in no significant differences in niacin content at reasonable corn yield levels.

4. Differences in the niacin concentration of corn grown on different farms or in different states were either not significant or unimportant.

5. Inbred lines differed widely in their niacin concentration, the range for 24 established inbreds being from 13.9 to 53.3 micrograms per gram.

6. Single-cross and double-cross hybrids tended to be intermediate between the parents, with the seed parent exercising more influence than the pollen parent. A few exceptions to this condition suggest that complicating mechanisms may exist.

7. The influence of the pollen parent, though less than that of the seed parent, is enough to require controlled pollination in any study of niacin concentration in corn.

8. Our results, with those of others reviewed, indicate two modes of inheritance for niacin concentration. One of these, multiple-factor inheritance, involves the joint action of many genes of small individual effects and with dominance lacking. This joint action is indicated as dominating control in the single and double-cross hybrids and in the selection experiments with Huffman. The other mode of inheritance is that reported (**6**) for the *Su su* alleles. Here, the *Su* (starchy) gene is dominant for lower niacin concentration over its *su* (sugary) allele. This dominance could be a pleiotropic effect. There is a suggestion (inconclusive) that the *Wx wx* alleles might operate similarly.

9. Three generations of selection in selfed lines of the Huffman variety established four families at higher and four families at lower concentrations.

10. The 15 S3 ears grown in 1946 and planted in 1947 to continue the three highest-niacin families, averaged 41.4 micrograms per gram. This average concentration exceeded the individual concentrations of all but one of the 1946 parent ears, and was nearly twice that (22.0) for the Huffman variety.

11. It was concluded that corn hybrids with niacin concentrations as high as 50 micrograms per gram could be developed. It was emphasized, however, that such hybrids would be useless unless they also yielded well and had other desirable characteristics. Their development, accordingly, would be complicated.

The writers are indebted to the Department of Biology of Princeton University for greenhouse and laboratory facilities in the early stages of the work, and to Mrs. Mary Ruth Pearlman and Miss Hope Robson for making the assays reported herein. The writers wish particularly to thank Dr. Robert R. Williams, Chairman of the Williams-Waterman Fund in the Research Corporation, for his kindly interest in furthering the investigations.

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NOTES

Reprint Orders.—Beginning with this issue of Plant Physiology all reprint orders will be billed from the office of the Executive Secretary-Treasurer, Dr. J. Fisher Stanfield, Miami University, Oxford, Ohio, and payment made to that office. Authors should place reprint orders with the editor at the time they return corrected galley to the editor's office. Shipment of reprints will be made to authors as heretofore. This new arrangement for billing reprints has been made in order to simplify accounts and expedite service since many orders require considerable bookkeeping. This new arrangement will also obviate the use of C.O.D. packages to members and will facilitate the handling of charges for changes in the galleys and reduce editorial overhead.

Corresponding Members.—At its Chicago meeting the American Society of Plant Physiologists elected the following four European botanists as corresponding members in recognition of their distinguished contributions to the science of plant physiology.

Professor F. G. Gregory.—Dr. Gregory, a Doctor of Science of the University of London and a Fellow of the Royal Society of London, is Professor of Plant Physiology at the Imperial College of Science and Acting Director of the Institute of Plant Physiology. Dr. Gregory's work has touched almost every phase of plant physiology but he is perhaps best known for his physiological studies in plant nutrition and his work on the physiology of development (photoperiodism, vernalization, and the hormonal regulation of growth). Gregory has also worked and written on such diverse subjects as energy relations of green plants, respiration, nitrogen, metabolism, transpiration, and stomatal behaviour. During his long association with the Institute of Plant Physiology when Professor V. H. Blackman was Director, Gregory has directed work and maintained a close connection with the Agricultural Research Stations at Cheshunt, Rothamsted, and East Malling. In these contacts with agriculture Gregory has blended most happily the spirit of pure research and the investigation of practical problems.

Professor Runar Collander.—Dr. Collander's name has long been familiar to all students of cell physiology. Apart from a period in Höber's laboratory at Kiel, Collander has done all his work at the Botanical Institute of Helsingfors, Finland. His earlier inquiries into the nature of membrane permeability contributed much to the then growing knowledge of the rôle of submicroscopic structure in the determination of permeability phenomena. Following Overton, Collander was early impressed with the role of fat solubility in the determination of cell permeability to non-electro-

lytes, but he brought to this field of work a strong interest in the application of physicochemical methods of measuring and comparing permeability with the molecular volumes and fat solubility of a variety of solutes. From the Botanical Institute of the University of Helsingfors has come a long series of monumental papers by Collander and his pupils and collaborators and these effectively document and contain the evidence for the "Lepord-Sieve" theory which is associated with his name. However, Collander—like his predecessor Overton—has always kept in mind the idea of an "active" as contrasted with a "passive" permeability and has also contributed to the knowledge of the unequal distribution of ions between the vacuoles of plant cells and the surrounding medium (for which the term "accumulation" is often used) and which seem not to be wholly explicable in terms of the passive permeability properties of the membranes.

Professor Albert Frey-Wyssling.—To most plant physiologists Dr. Frey-Wyssling will best be known for his Protoplasma Monograph on the Submicroscopic Morphology of Protoplasm and its Derivatives published in 1938. He is a member of the staff of the Pflanzenphysiologisches Institute der Eidgenössischen Technischen Hochschule, Zurich. From the early 1920's Frey-Wyssling has written on various topics which show his keen interest in the submicroscopic structure of the substances which go to make up the components of cells. The application of the polarizing microscopic and of x-ray diffraction in the interpretation of micellar structure of cell walls and cell inclusions has been his special interest. Plant physiologists recall that Frey-Wyssling has also interested himself in the more conventional macroscopic morphology, notably some aspects of vascular differentiation.

Professor Hans Bürstrom.—In electing Dr. Bürstrom of the Botanical Laboratory, University of Lund, Lund, Sweden, to corresponding membership the Society honors one who, in investigating the practical problems of agriculture, is maintaining the best standards of academic research. From an early association with Dr. Lundegardh stemmed Bürstrom's interest in the problems of respiration and of mineral nutrition. Other investigations on cell enlargement, buffer systems of plants, auxin effects, and related subjects all form part of a wide interest in cell physiology. More recently, however, Bürstrom has reopened the fundamental problems of nitrate assimilation and the relations between photosynthesis, nitrogen metabolism, and growth of plants.

Earl Steinford Johnston.—Dr. Johnston died at his home in College Heights, Maryland, on December 17, 1947, after a painful illness. Dr. Johnston was born February 5, 1889, at Quarryville, Pennsylvania. He received the Ph.B. degree from Dickinson College in 1913 and the M.A.

degree from the same institution the following year. After a year as science instructor in the Pennington School for Boys he accepted an assistantship at Johns Hopkins University to work in the laboratory of Professor Burton E. Livingston. During the summer of 1915 he served as assistant in the Desert Laboratory of the Carnegie Institution.

After receiving his Ph.D. degree from Johns Hopkins University in 1917, Johnston joined the Maryland Agricultural Experiment Station staff as associate in plant physiology, later becoming associate professor of plant physiology in the University of Maryland. His research during the period at Maryland centered chiefly upon the problems of water relations of fruit buds particularly as relating to dormancy and hardiness, and of the salt nutrition of the potato. During a sabbatical year (1926–1927) spent in the laboratory of Professor D. R. Hoagland in California, his interest was drawn to the role of boron in plant nutrition. Johnston was able to prove the necessity of boron for the tomato and potato and later made studies of its mobility in the plant and of the effects of its deficiency upon composition and structure of the tomato. His research contributed substantially to recognition of the general indispensability of boron in plant nutrition.

At Maryland his background of broad training in physical science was utilized to good advantage in developing one of the pioneer courses in biophysics as related to plant physiology. Throughout his career he maintained a keen interest in physical methods as aids in plant physiology and was always delighted when called upon to design or improve some piece of equipment.

In 1929 Johnston became consulting plant physiologist to the Division of Radiation and Organisms then newly established at the Smithsonian Institution in Washington, D. C., with a research assignment on the biological effects of radiant energy. He became a full time member of the staff in 1931, assistant director in 1933, and director of the Radiation Division some years later. At the Smithsonian Institution Johnston was interested in and, as director, encouraged a wide variety of studies relating to the broad program of his division. Research in which he engaged actively included investigations on photosynthesis and the aerial fertilization of plants, phototropism, plant development in artificial light with special attention to wavelength balance and the effects of infra-red and polarized radiations, and effects of radiant energy on growth substances, respiration and morphogenesis. One of the best known results of these studies is his careful determination of the action spectrum for the phototropic response.

His indefatigable patience and persistence in surmounting experimental obstacles and his thoroughness in the laboratory served as inspiration to his coworkers. His enduring kindliness and enthusiasm endeared him to all who were associated with him. Johnston was a firm believer in the value of making available to the layman the findings of scientific research

and devoted much time and effort to the preparation of popular articles, lectures, and museum exhibits to this end.

He was an active member of the Botanical Society of Washington which he served as vice-president and as president. In addition to numerous other professional affiliations, Dr. Johnston actively participated in the work of the American Society of Plant Physiologists from the time of its organization. He served outstandingly as secretary and vice-president of this society from 1944 to 1946 as well as chairman and member of several important committees. Dr. Johnston's passing leaves his friends and colleagues with a keen sense of personal loss. His judicious counsel, unflagging service and capacity for friendship will long be cherished by all those privileged to know him.

George Walter Pucher.—Members of the American Society of Plant Physiologists will be grieved to learn of the sudden death at the early age of forty-nine years from a myocardial infarction of Dr. George W. Pucher in New Haven, Connecticut, on November 20, 1947.

Dr. Pucher was born in Lake LaBarge, Alaska, on May 13, 1898, and was educated at the University of Washington where he received the B.S. degree in 1917 and the M.S. degree in 1918. After two years of advanced study at Yale (Ph.D. 1920), he was employed for a year by the National Aniline and Chemical Co., and then became successively biochemist, assistant professor, and associate professor of biochemistry at the Buffalo General Hospital, N. Y. He joined the staff of the Connecticut Agricultural Experiment Station in New Haven as associate biochemist in 1928.

Dr. Pucher was an outstanding laboratory investigator. His plans always took note of every possibility and no essential precaution or control was overlooked. His records were complete to the smallest detail. The numerous analytical methods he devised in the course of his studies of plant metabolism are characterized by extraordinary ingenuity and simplicity. Their application, particularly in the field of excised leaf culture, has greatly broadened present-day knowledge of the biochemical behavior of plants.

The following is quoted from the minutes of the December 1st, 1947, meeting of the Experiment Station Council: "The Staff of the Connecticut Agricultural Experiment Station has learned with deepest regret of the death of Dr. George W. Pucher of the Department of Biochemistry. Dr. Pucher served this Station for nineteen years and had established himself as an outstanding and widely recognized authority in the field of plant metabolism. His work on analytical methods is particularly noteworthy since several of these methods are in use in laboratories in all parts of the world and have led to striking advances in many fields of biochemistry. His discovery of isocitric acid in Bryophyllum plants and his identification of crassulacean malic acid as isocitric acid solved a problem that has puzzled plant biochemists for seventy years. This discovery also is one

which bears directly on the work of biochemists in other fields since isocitric acid has recently become a substance of wide interest and importance. Dr. Pucher's sudden death is more particularly a matter for grief to this Station since it removes from among us a man whom we greatly admired for his personal qualities. His happy good nature won friendship and his industry and devotion to his work won respect. He will be greatly missed by all of the Staff and he leaves a place that it will be impossible entirely to fill."

Dr. Pucher is survived by his wife, who was Eleanor McKay of New Haven, a daughter, Mrs. Howard Sanders of Springfield, Ohio, and a son, George Eric Pucher, a student at the University of Vermont.

David Lawrence Taylor.—Dr. David L. Taylor was born November 16, 1915, at Fargo, North Dakota. After receiving his B.S. at North Dakota in 1938 and his Ph.D. at Columbia University in 1942, Dr. Taylor was sent to Camp Detrick, Maryland, in January, 1944, where he served for two years in the Chemical Corps. He was discharged from the Army in January, 1946, with the rank of major. He then went to the University of Chicago where he was Assistant Professor in the Department of Botany. In September, 1947, Dr. Taylor took a position as Assistant Professor in the Department of Botany at the University of Illinois where he remained until his death December 6, 1947. Dr. Taylor published a series of four papers on observations on the growth of certain plants in nutrient solutions containing synthetic growth-regulating substances while he was at Camp Detrick. At the University of Chicago Dr. Taylor's main interest was research on plant-growth regulators. He was married to Helen Marie Bonde of Fargo, North Dakota, in 1938 and a son was born to them in 1945.

Professor Ludwig Jost.—The American Society of Plant Physiologists records with sorrow the death, at the age of eighty-one years, of Dr. Ludwig Jost on February 22, 1947, at his home in Heidelberg, Germany. He is survived by his wife, Kathrina, and four daughters. In recognition of Professor Jost's distinguished contributions to plant science and to plant physiology in particular, the American Society of Plant Physiology elected him a corresponding member in 1938. After retirement for age from his professorship and direction of botanical services at the University of Heidelberg, Dr. Jost continued his professional work for many years. His record for brilliance as an investigator and teacher has seldom been equalled in the annals of his profession. He contributed substantially to the high repute so long enjoyed by Heidelberg University among scientists throughout the world. Many of his publications are classics in plant science and they stand as an enduring tribute to Dr. Jost and his distinguished professional career.

The Fulbright Act.—The following summary has been prepared in response to a growing interest in the Fulbright Act and in particular to the opportunities it affords in all fields of teaching and advanced research in institutions of higher learning. The Fulbright Act (Public Law No. 584) authorizes the Department of State to use a portion of the foreign currencies resulting from the sale of surplus property abroad for purposes of educational interchange and activities with foreign countries. At present agreements have been signed with only two countries—China and Burma; but negotiations are in progress with the following: Australia, Austria, Belgium, Czechoslovakia, Egypt, Finland, France, Greece, Hungary, Iran, Italy, the Netherlands, the Netherlands East Indies, New Zealand, Norway, the Philippines, Siam, Turkey, the United Kingdom, and it is expected that other countries may be added to the list. It should be stressed that since the money available is only in foreign currencies and is not convertible to American dollars, individual arrangements must be made for each American participating in the program for such dollar balances as he will require to meet his family needs and other obligations in the United States during the period of his absence abroad.

While the term educational interchange may be interpreted very broadly, the following amplification will serve as a more useful guide to the types of activities envisaged: Aid in international reconstruction by assisting foreign countries to secure the services of Americans with specialized knowledges and skills and to assist the peoples of these countries to understand the American people, their achievements and their ideals. Provision for Americans to study, teach, and conduct research abroad in connection with American schools or with institutions of higher learning, and to add to the American store of knowledge of foreign areas, peoples and cultures.

Opportunities for a limited number of foreign students to study in American institutions abroad and to assist foreign students and teachers to engage in educational activities in the United States by paying for their transportation wherever foreign currencies can be used for this purpose. Under the terms of the Fulbright Act, a Board of Foreign Scholarships is charged with the responsibility of selecting individuals and institutions which will participate under the act and with the supervision of the exchange program. The Board is composed of individuals representing a wide range of educational and cultural interests in addition to representatives of the government agencies most concerned.

The Board has delegated responsibility for preliminary screening of applicants for grants to three agencies:

1. The Institute of International Education for those wishing to study in foreign institutions, primarily at the graduate level;
2. The Office of Education for those wishing to teach abroad in national elementary and secondary schools;
3. The Conference Board of Associated Research Councils for those wishing to teach, lecture or offer technical instruction in connection

with institutions of higher learning or to pursue studies and research abroad at the post-doctoral level. The Conference Board will also screen applicants for teaching positions in American elementary and secondary schools abroad.

For discharging this responsibility, the Conference Board has established a Committee on International Exchange of Persons with offices at the National Academy of Sciences Building, Washington, D. C. All inquiries concerning the exchange of professors, lecturers, specialists and research scholars at the post-doctoral level, and inquiries concerning opportunities for teaching in American primary and secondary schools abroad including requests for application forms should be addressed to: The Executive Secretary, Committee on International Exchange of Persons, Conference Board of Associated Research Councils, 2101 Constitution Avenue, Washington 25, D. C. Inquiries relating to graduate student exchanges should be addressed to: Institute of International Education, 2 West 45th Street, New York 19, N. Y. All inquiries relating to national primary and secondary school teaching should be addressed to: The Office of Education, 4th and Independence Ave. S.W., Washington, D. C. Inquiries relating to exchanges other than those concerned with the Fulbright Act should be addressed to: The Division of International Exchange of Persons, Department of State, Washington 25, D. C.

The Essentials of Plant Biology. FRANK D. KERN. Harper & Brothers, 49 East 33rd Street, New York City. 1947. Pp. vii + 440. $4.00.

This new textbook is designed for a one semester course in elementary botany. The book employs a functional approach yet presents basic botanical concepts in a progressive sequence which enables beginning students to obtain readily a clear understanding of the unity of plant life. The text comprises two major parts; the manifestation of life stressing individual maintenance and the perpetuation of life covering various aspects of racial preservation. The overview of the plant kingdom is presented as a fifty page supplement on the great groups of plants. Attention throughout is centered upon plant activities and interpretation of life phenomena. The broad concepts of plant life bearing on human culture are expertly merged with the role of plants in contemporary affairs.

The book is profusely illustrated with two hundred and sixty figures most of which are new and especially well adapted to the full development of textual concepts. Several excellent full page color plates contribute substantially to clarity of detail. The cuts are of uniformly high quality both in choice of material and excellence of reproduction. The format and headings are material aids to the organization of subject matter and the author's style of presentation provides unusual clarity and interest for student readers. The author has achieved readability without sacrifice of scientific accuracy by minimizing the use of technical terminology

and introducing it with care. Student interest has been attained by good organization, choice of interesting content, good illustrations, and diversity of references to practical applications of principles. The book is quite different from most of its kind and for a one semester text it gives the reader an exceptionally thorough grasp of plant science and its importance in modern life. The sixteen page index is very complete and greatly facilitates reference use of the text.

The author has drawn ingeniously upon his rich first hand acquaintance with the world flora and his long experience in presentation of the various disciplines of plant science. The excellence of content and style of the book will appeal to students and instructors.

Growth of Plants: Twenty Years' Research at Boyce Thompson Institute.—WILLIAM CROCKER. Reinhold Publishing Corporation, 330 West 42nd Street, New York 18, New York. 459 pages, 1948. $10.00.

This book is a critical summary of researches conducted at the Boyce Thompson Institute since its establishment in 1924. The main title, growth of plants, is justified not only by the wide scope of the institute's work on that subject but by inclusion of related outside studies in the field of plant growth. The first two chapters describe the founding of the institute, its objectives and some of its early problems. Two very comprehensive chapters deal with life span and dormancy of seeds, and two with the effect of gases upon plant growth. Separate chapters are devoted to hormones, bud dormancy, cell membranes, insecticides and fungicides. A concluding chapter discusses a miscellany of brief or minor projects in which the institute has been interested. In addition to 754 citations to original papers the book contains 171 figures, many of which are in color. Many figures and 48 tables provide an abundance of original data. Separate author and subject indices facilitate easy reference use of the book. The book is the chronicle of the author's efficient stewardship of the institute and an imposing record of its achievements in the field of plant growth. The author is assured the keen appreciation of plant scientists for the arduous task of assembling, thoroughly collating and critically evaluating so vast a body of important data.

Hormones and Horticulture.—GEORGE S. AVERY, JR. and ELIZABETH B. JOHNSON. McGraw-Hill Book Company, New York City, New York. 326 pages, 1947. $4.50.

This timely book deals primarily with the practical applications of special chemicals in the control of plant growth. The authors stress current efforts to regulate plant growth by application of minute amounts of growth-controlling phytohormones as a major feature of a new era in agriculture. They have assembled and collated a great many data from widely scattered sources on the theory and use of growth substances. Specific directions for their use and critical evaluation of results constitute a major contribution of

the book. With a view to thoroughness, the authors have not limited the discussion to phytohormones in the narrow sense but include the use of many other compounds which in low concentrations are capable of inducing marked plant response.

The book describes various chemicals in relation to the rooting of cuttings, use of blossom-thinning sprays, control of fruit abscission, parthenocarpy, seed germination and dormancy, activation of dormant vegetative organs, the use of colchine and comparable stimuli in the production of ploidy, and the role of new herbicides in agriculture. The extensive bibliography plus very complete subject and author indices add considerably to the utility of this important practical compendium on plant response to growth substances.

Plants and Environment.—R. F. DAUBENMIRE. John Wiley and Sons, 440 Fourth Avenue, New York 16, New York. 424 pages, 1947. $4.50.

This textbook of plant autecology deals with relations between plants and environment and is intended for students majoring in botany and its applied disciplines. The content cuts across those phases of geology, soils, climatology, zoology, chemistry and physics which are related to plant ecology, structure, function and evolution. The book provides a basis for the etiology of distribution and understanding of dynamic interrelationships. It aims at a holistic viewpoint and logical synthesis of ecological data from various fields of science. While emphasis is upon principles, numerous examples of their practical applications are included. The major topics comprise a sequential discussion of soil, water, temperature, light, atmosphere, fire, and biotic factors with their integration in chapters on the environmental complex, ecologic adaptation and plant evolution. The book has an excellent format and readily comprehensible style. It is well illustrated. It carries a bibliography of 612 citations and a comprehensive, cross-referenced index.

Botanik der Gegenwart und Vorzeit.—K. F. W. JESSEN, 1948 reprint in German edited by HANS VERDOORN. Chronica Botanica Company, Waltham 54, Massachusetts. 495 pages, 1864. $6.00.

There can be little doubt that Jessen's Botanik der Gegenwart und Vorzeit, little known as it may be at present, is the best concise, all-around history of botany ever attempted. Jessen's Botanik was published in 1864, eleven years before Sach's Geschichte. From the point of view of the historian of science, Jessen's book is unique for its cultural approach. In many other ways it is superior to Sach's history (which in its turn remains unique for its treatment of the development of nineteenth century plant physiology).

Plant Biology, SECOND EDITION.—PAUL WEATHERWAX. W. B. Saunders Company, West Washington Square, Philadelphia 5, Pennsylvania. 451 pages, 1947. $4.25.

The new edition of this well known text is considerably improved in format and content. Extensive revisions have brought up-to-date the discussions of growth substances, bacteria, viruses, antibiotics and plant formations

in relation to ecology. The revisions reflect recent notable advances in plant physiology, especially in relation to bacteria and fungi.

Format, organization and numerous illustrations which are excellent as to subject matter and far superior to those of most texts achieve unusual interest and lucidity of content. An extensive glossary of botanical terms and a complete index further augment the usability of the book. Like its predecessor, the second edition is especially designed for beginning and non-professional students and it will be welcomed by instructors who conduct general education courses in botany and biology.

Cottonseed and Cottonseed Products: THEIR CHEMISTRY AND TECHNOLOGY.—Edited by ALTON E. BAILEY. Interscience Publishers, 215 Fourth Avenue, New York 3, New York. 936 pages, 1948. $17.50.

This publication is the most recent in the publisher's Fats and Oils series of monographs dealing with the chemistry and technology of oils and related substances. The book begins with a historical account of cotton and the cottonseed industry in the United States, followed by a résumé of production and consumption of cottonseed products. Physiologists will find the section on composition and characteristics of particular interest as it collates in a dependable way major works on structure and processes of cottonseed, its pigment, oil and protein components. Four sections on grading and processing cover primarily the technology of cottonseed and its products. Several sections are devoted to the role of cottonseed and its derivatives in human and livestock nutrition, all of which collate the most important recent biochemical developments. Author and subject indices are very complete, thus contributing considerably to the reference value of the book.

Advances in Enzymology, Volume VII.—Edited by F. F. NORD. Interscience Publishers, 215 Fourth Avenue, New York 3, New York. 665 pages, 1947. $8.75.

This latest edition of the series carries several sections of special interest to plant scientists, especially those on Permeability and enzyme reactions by S. C. Brooks; Properties of protoplasm with reference to the influence of enzymatic reactions by William Seifriz; Bacterial luminescence by Frank H. Johnson; Distribution, structure, and properties of the tetrapyrroles by S. Granick; Interrelations in microorganisms between growth and the metabolism of vitamin-like substances by Henry McIlwain; Antibacterial substances from fungi and green plants by Frederick Kavanagh; and Recent progress in industrial fermentation by F. M. Hildebrandt. In addition to the usual author and subject indices for volume VII, this book carries cumulative subject and author indices to volumes I to VII inclusive.

Annual Review of Biochemistry, Volume XVI, 1947.—Edited by J. MURRAY LUCK, HUBERT S. LONG and GORDON MACKINNEY. Annual Reviews, Incorporated, Stanford University P. O., California. 740 pages. $6.00.

Plant physiologists will find most of the twenty-five sections of this vol-

ume of considerable interest, especially the following: Biological oxidations and reductions; Proteolytic enzymes; Chemistry of carbohydrates and lipids; Fat and water soluble vitamins; Nitrogenous constituents and mineral nutrition of plants; Growth-substances in higher plants; Bacterial metabolism; Use of isotopes in biochemical research. Both author and subject indices are very complete. This volume also carries a topical and author table of contents to volume XVII for 1948.

Chemical Architecture.—Edited by R. E. BURK and OLIVER GRUMMIT. Interscience Publishers, 215 Fourth Avenue, New York 3, New York. 202 pages, 1948. $4.50.

This monograph comprises volume five in the publisher's well-known lecture series on Frontiers in Chemistry and is devoted to theoretical and practical applications of the physico-chemical aspects of molecular systems. A distinguished group of authors have contributed sections on molecular geometry in the field reaction mechanism, dipole moment, structure of coordination compounds, X-ray studies of randomness, light scattering in polymer solutions, and the nature of inorganic gels. Biographical sketches and portraits of the contributing authors contribute considerably to the interest of this volume.

Plant and Soil, Volume I, 1948.—Edited by D. I. ARNON, J. BAEYENS, F. C. GERRETSEN, E. G. MULDER and A. C. SCHUFFELEN. Martinus Nijhoff, Publisher; The Hague, Holland. 20 guilders per volume.

The first number of this new international journal of plant nutrition, plant chemistry, soil microbiology and soil-borne plant diseases has recently appeared. The editors envisage for it prompt publication on an international basis of researches which center around the plant and its relations to the soil. Its objective is to assemble between the covers of one periodical data on related aspects of experimental work in plant physiology, biochemistry, plant nutrition, soil science and soil microbiology in terms of plant-soil interrelationships. Papers may be published in English, French or German. The first number contains six excellent papers by authors from various parts of the world. Plant physiologists will follow with interest and profit the future issues of this unique periodical.

Trees and Toadstools.—M. C. RAYNER. Rodale Press, Emmaus, Pennsylvania. 91 pages, 1947. $2.50.

A brief popular account of fungi and the occurrence and role of mycorrhizae. Attention is given fungi in relation to orchids, conifers, and deciduous tree roots, with a historical account of development of knowledge concerning mycorrhizae and symbiosis.

Nature and Prevention of Plant Diseases.—K. STARR CHESTER. The Blakiston Company, 1012 Walnut Street, Philadelphia, Pennsylvania. 525 pages, 1947. $5.00.

The book is designed primarily for college students taking a single course in plant pathology. Emphasis is placed on recognition, understanding and prevention of plant diseases. The most important diseases of crops widely grown in the United States are described together with generally approved methods of control. The text is well illustrated and contains a good glossary and index.

The Land and Wildlife.—EDWARD H. GRAHAM. Oxford University Press, New York City. 232 pages, 1947. $4.00.

This book discusses the problems of land and wildlife with thoroughness and scientific soundness. It stresses the fact that practical wildlife management is accomplished through good land use. The author discusses the wildlife heritage of the United States and various conservation practices in diverse wildlife habitats, such as swamps, ponds, stream banks, field borders, hedges, gulleys, crop land, pasture, woodlots, forests, and ranges. Three chapters are devoted to wildlife prospects, its cost and benefits, and the general relation between wildlife, land, and people. The text contains a carefully selected bibliography. The book is useful to professional workers, students of conservation and land owners.

An Introduction to Agricultural Chemistry.—N. M. COMBER, H. T. JONES, and J. S. WILLCOX. Longmans, Green, and Company, 55 Fifth Avenue, New York 3, New York. 315 pages, 1947. $2.50.

This book is a concise discussion of the major subjects of agricultural chemistry. The main chapters are Soils, Fertilizers, and Animal Nutrition, covering plant nutrition, chemistry of the major constituents of plants and animals, and methods of field experimentation. Excellent treatment is given to the formation, physical structure, and colloidal behavior of soils. The sections on plant nutrition and the determination of the availability of various nutrients in soils are very useful.

The book is well organized, the style is clear and straight forward, and the index is very good. References are given by name only, without literature citations.

The Chemical Composition of Foods.—R. A. MCCANCE and E. M. WIDDOWSON. Chemical Publishing Company, 26 Court Street, Brooklyn 2, New York. 156 pages, 1947. $3.75.

This volume gives the results of chemical analyses of British foods conducted under the sponsorship of the Medical Research Council. The first part of the book gives recipes for prepared foods and the chemical composition of raw and prepared foods per 100 grams. The proportions of edible material, water, nitrogen fractions, protein, fat, and carbohydrate and mineral content are discussed. A table on the phytic acid phosphorus contents of some foods and a very thorough index complete the book. The organization of the tables is clear and the printing and binding of the book are excellent.